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AUTHORITY

RADC ltr, 1 Jul 1966

RADC-TDR-63-140
ASTIA Document No. AD-

Final Report

CRITERIA FOR DISCARD-AT-FAILURE MAINTENANCE

by

Eugene G. Wrieden

Prepared for

Rome Air Development Center
Research and Technology Division
Air Force Systems Command
United States Air Force
Griffiss Air Force Base
New York

March 1963

IBM No. : 63-928-7
Contract No. : AF30(602)2681

IBM Corporation
Federal Systems Division
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FOREWORD

This report covers the work performed by the IBM Space Guidance Center under Contract No. AF 30(602)-2681. The contract was issued under Project 5519, Task 551901, and was administered by the Maintainability Group, Reliability and Maintainability Branch, Applied Research Laboratory of the Rome Air Development Center, Griffiss Air Force Base, New York. The RADC project engineer was Mr. E. P. Simshauser.

The study was conducted in the Maintainability Engineering Department, and Mr. E.G. Wrieden was responsible for the technical direction of the program. The study was begun in February 1962 and was completed in February 1963.

The author is indebted to Mr. J. F. Griffin for his active part in this effort and to Messrs. G. Barbieri, R.E. Redfern, J. Schneider, O.B. Shafer, M.A. Young and Dr. M.J. Marcus for the helpful consultations provided during the study.

The author would also like to express his appreciation to Mr. E.P. Simshauser for his active support during the program and his assistance in establishing contacts for the data required for the study. The constructive criticism provided by Mr. F.D. Mazzola of RADC also benefited the study.

A final note of thanks is due to Mr. J.J. Baker for his assistance during the preparation of this report.

ABSTRACT

The results of a study to define the significant factors which affect the feasibility of discard-at-failure maintenance (DAFM) for USAF electronic equipment are presented herein. Included is a mathematical model which can be used to evaluate the total resource cost for DAF and repairable modules. To ensure model usability, a simple step-by-step procedure is presented which minimizes the requirement for complex mathematical manipulations. In addition to determining which is the more economical approach (i.e., design for DAF or design for bit and piece repair), the model provides a means of defining the optimum DAF module size.

Also included are discussions of recommended packaging techniques for DAF modules, the impact of microminiaturization on DAFM, and criteria for DAFM design.

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INTRODUCTION

Section I

INTRODUCTION

This final technical report describes the results obtained by studying the major factors influencing the feasibility of the discard-at-failure maintenance (DAFM) concept. The objectives of this one-year program, sponsored by the Rome Air Development Center under Contract AF 30(602)-2681, were:

- To investigate the major factors which influence the feasibility of the DAFM concept.
- To develop a useable mathematical model which (1) describes the influence of these factors on the total resource cost of discard and repairable modules, and (2) determines the optimum value of discard-at-failure (DAF) modules to obtain maximum economic advantages from this concept when it is used.
- To recommend DAFM packaging techniques which will combine the significant factors affecting this maintenance concept.
- To determine the effect of microminiaturization on DAFM.

A. BACKGROUND

Over the past two decades, the cost of maintaining military equipment has risen at an alarming rate. Present military maintenance expenditures have been estimated at 33 million dollars a day. During this same period, equipment availability has decreased markedly. For a number of years, discard-at-failure maintenance (DAFM) has been suggested as a possible means of alleviating the problems of rising maintenance costs and decreasing availability. As a result, this subject has been treated on both a qualitative and a quantitative basis in a number of studies.

One of the more significant studies was performed by the Collins Radio Company for the Rome Air Development Center. This study (completed in 1958) established that the design for DAFM was feasible, and would result in considerable savings in total resource costs over a design for repair by detail part replacement. Similar studies, resulting in essentially the same conclusions, were performed by the National Bureau of Standards for the Navy's Bureau of Aeronautics and the Jet Propulsion Laboratory for the Army's Ordnance Corps. In these studies, as well as in studies performed by various

agencies of the Air Force Logistics Command, mathematical models to evaluate the economics of the discard-repair decision were developed. However, these mathematical decision models had one or more of the following shortcomings:

- Extremely complex, thus reducing the useability of the model.

- Applicable to only a limited variety of equipment types.

- Required input quantities for the model are only available at the provisioning stage of the equipment life cycle, and thus, the model is a provisioning decision tool rather than a design decision tool.

Thus, a requirement existed for a logical follow-on to these earlier studies. This follow-on study was needed to develop a mathematical model which was simple to use, applicable to Air Force electronic equipment in general, and could be applied during the early equipment design phases. In addition, design criteria were needed to guide the design of modules for DAFM such that the advantage over modules designed for and maintained on a piece part basis is realized and maximized.

Another factor, contributing to the requirement for a follow-on study of this type, was the advent of microminiaturization. The various microelectronic approaches either preclude bit and piece repair, or make such repairs extremely undesirable because of high susceptibility to damage during module repair operations. Thus, operational microminiaturized equipment would normally employ a DAFM philosophy.

In the relatively small amount of literature which discusses maintenance aspects of microminiaturized equipment, the DAF module size is normally considered as equivalent to a circuit. However, this "decision" is based primarily on aspects of design, manufacturing and standardization rather than on the over-all economics of the envisioned operational and maintenance environment. Under the present conditions of low production volume, costs are of such a level that this size of microminiaturized DAF module could very well result in minimum maintenance costs. However, as production volume increases and module costs decrease, the optimum DAF module size may, under certain conditions, consist of an assembly of many individual circuits. Therefore, an urgent need exists for a generalized decision tool for defining an optimum microminiaturized DAF module size.

The general form of the mathematical model developed in this study is applicable to microminiaturized equipment. However, certain precalculated constants are supplied with the model. Since these constants are based on

data from existing USAF equipment, direct application of the model, using these precalculated quantities, is not recommended. The model should be re-evaluated and updated when operational data becomes available on micro-miniaturized equipment.

B. STUDY APPROACH

DAF criteria for electronic equipment can be established at the following levels:

- Trade-offs between the support costs accumulated by a repair process and the costs incurred by procuring replacement hardware.
- Second-order effects on the cumulative costs of support, such as: (1) the decrease in reliability which may result from the repair process or handling during shipment, (2) the impact of a 90-day repair turn-around on the size of the pipeline spares inventory as compared to the inventory required by a DAF policy and (3) the costs of capitalizing, or of shutting down a repair facility.

A properly defined DAF policy makes it clear that test and physical access need not be provided for maintenance in the packaging and functional design of some portions of the prime equipment. This, in turn, has implications for component density, the feasibility of coating and encapsulation techniques, the ratio between connections and connectors, component selection, circuit design, and self-test circuitry. The discard-at-failure policy can have important implications for support system planning, reducing the need for test equipment, certain maintenance skills, and sometimes eliminating an entire echelon of maintenance.

Of the several study programs previously conducted on DAFM, most have been concerned with either a specific item of equipment or the initial provisioning stage of the equipment life cycle when the equipment has already been designed. This study was conducted to develop a decision model which is applicable to AF electronic equipment in general, and which can be used during the early design phases of a development program.

To accomplish the objectives previously mentioned, the program was divided into three major phases as follows:

- Phase I - Assemble reliability, cost, and maintenance data on existing modularized equipment, and obtain reports on previous studies relating to the DAFM concept.
- Phase II - Review and analyze the data obtained in Phase I.
- Phase III - Formulate, test and modify the mathematical model.

Section II

FACTORS AFFECTING THE REPAIR-DISCARD DECISION

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FACTORS AFFECTING THE REPAIR-DISCARD DECISION

The following paragraphs contain a brief discussion of the major factors affecting the decision to repair or discard.

A. RELIABILITY

Reliability is a major factor affecting a repair or DAF decision. The mathematical expression for the reliability of equipment is a function of the failure rate (or its reciprocal, mean-time-between-failures). From a maintenance viewpoint, it is the failure rate which is of interest, since this is one of the factors determining the number of malfunctions which will occur. For the repair case, the number of malfunctions which occur determines the maintenance workload, number of pipeline spares, and number of bits and pieces required. For the DAF case, the number of malfunctions determines the number of discard-modules required. Therefore, all other factors being equal, one can afford to discard a highly reliable module upon failure more readily than a highly unreliable module.

The effect of the repair operation on the reliability of the module also affects the feasibility of DAFM. Reduced reliability, due to improper module repair, may require larger quantities of pipeline spares and additional equipment to maintain the same level of availability.

B. COST OF THE MODULE

The basic module cost is one of the major factors of the DAFM concept. Module cost includes the cost of material and parts, fabrication and assembly, quality control inspection and test, scrap and rework, overhead for the manufacturer, and development.

The cost of a module depends upon the following:

- Number of detail parts in the module
- Types of detail parts (i. e., tubes, transformers, resistors, transistors, etc.)
- Type of circuitry (i. e., tube, transistor, microminiature, etc.)

- Quality of detail parts (This, in turn, is dependent on equipment reliability, performance, and environmental requirements.)

- Production quantities

For a given piece of equipment, the last three factors are fixed parameters. The types of detail parts used will normally be dictated by reliability and performance considerations. Thus, in the evaluation of optimum DAF module cost, the only independent variable is the number of detail parts in the module, so module cost may be thought of as interchangeable with number of detail parts as a measurement of physical size of the module.

C. POPULATION

The term "population" refers to the total number of items in service. It is equal to the product of number of items per piece of equipment, number of pieces of equipment per site, and number of sites.

Population, another of the factors determining the number of malfunctions which will occur, interacts with many of the factors affecting the discard-repair decision. Module cost will generally decrease as population increases. Similarly, increasing population will tend to decrease unit repair costs because a large population will result in a mass repair operation as opposed to a "job-shop" repair operation if the population is small.

D. DISTRIBUTION COSTS

These costs include storage and transportation connected with the spare parts supply and depend on:

- Volume and weight of the parts

- Number of storage locations

- Number of operating sites

- Relative locations of supplier and user

- Mode of transportation

The last three factors will be independent of whether or not a DAFM philosophy is employed. The first two factors however will depend on the maintenance philosophy.

A more subtle distribution cost difference between the DAF and the repairable case is the costs resulting from damage due to handling. A discard-module should be less susceptible to such damage since it can be strengthened by potting or encapsulation.

E. REPAIR COSTS

These costs cover the manpower and facilities needed to maintain the equipment. Manpower costs include direct labor (i. e., technician pay, subsistence and pro-rated training costs), and indirect labor performed by direct labor personnel (technicians) as well as indirect labor personnel (administrative, supervisory and supply personnel). Facilities costs include pro-rated costs of tools and test equipment (including the cost to maintain the tools and test equipment), publications, buildings, and expendables such as wire, solder, etc.

F. ENTRY AND MAINTENANCE COSTS OF LINE ITEMS

The costs to establish and maintain a line item in the supply system include such factors as:

- Data acquisition for identification
- Processing of federal item identification
- Cataloging and other documentation
- Warehousing and inventory control
- Maintenance of the Material Repair System for repairable items

The range and quantity of repair parts are directly reflected in terms of dollars and cents of line item entry and maintenance costs. Therefore, this cost category represents a major difference between the repair and discard maintenance philosophies.

Another factor which enters into this major cost category is the costs incurred when future procurement of spares or replacement modules involves redesign or retooling to produce items not available off the shelf. The economic effect of engineering changes which may obsolete on-hand-spares stocks is another factor to be considered.

G. TIME

Time enters into the discard-repair decision in several ways. First, is operating time, which together with failure rate and population, determines the number of maintenance actions to be performed. Secondly, is repair time, which together with the number of maintenance actions and technicians needed to make the repair, determines the amount of manpower expended in repair activities.

Another time element is turn-around-time; the elapsed time between removing a failed item and the repair and return-to-stock of the item. Spares must be stocked to cover all the failures that are likely to occur during this time period.

Section III

DESCRIPTION OF THE MATHEMATICAL MODEL

Section III

DESCRIPTION OF THE MATHEMATICAL MODEL

A. MODEL CHARACTERISTICS

The mathematical model developed under this study has the following characteristics:

- Adaptable for use during the early design phases of a development program.
- Highly flexible to: (1) account for variations in the maintenance plan, and (2) permit up-dating of the model constants as the equipment in the AF inventory changes.
- Capable of quantitatively defining which of the two alternatives, module repair or DAF, is more economical.
- Ability to select the optimum DAF module part density.

A model with strong predictive powers is needed for use during the early design phases.

The form of the model becomes extremely important for future up-dating of the model parameters. At a detailed level, the model could be expressed in a variety of forms. However, a number of such forms would require extensive data collection efforts for any up-dating activity, and in some instances might even imply revisions to existing accounting and record-keeping systems.

B. MODEL DESCRIPTION

The most general form of the model is shown in Figure 1. The shred-out of the model is carried through three successive levels of expansion.

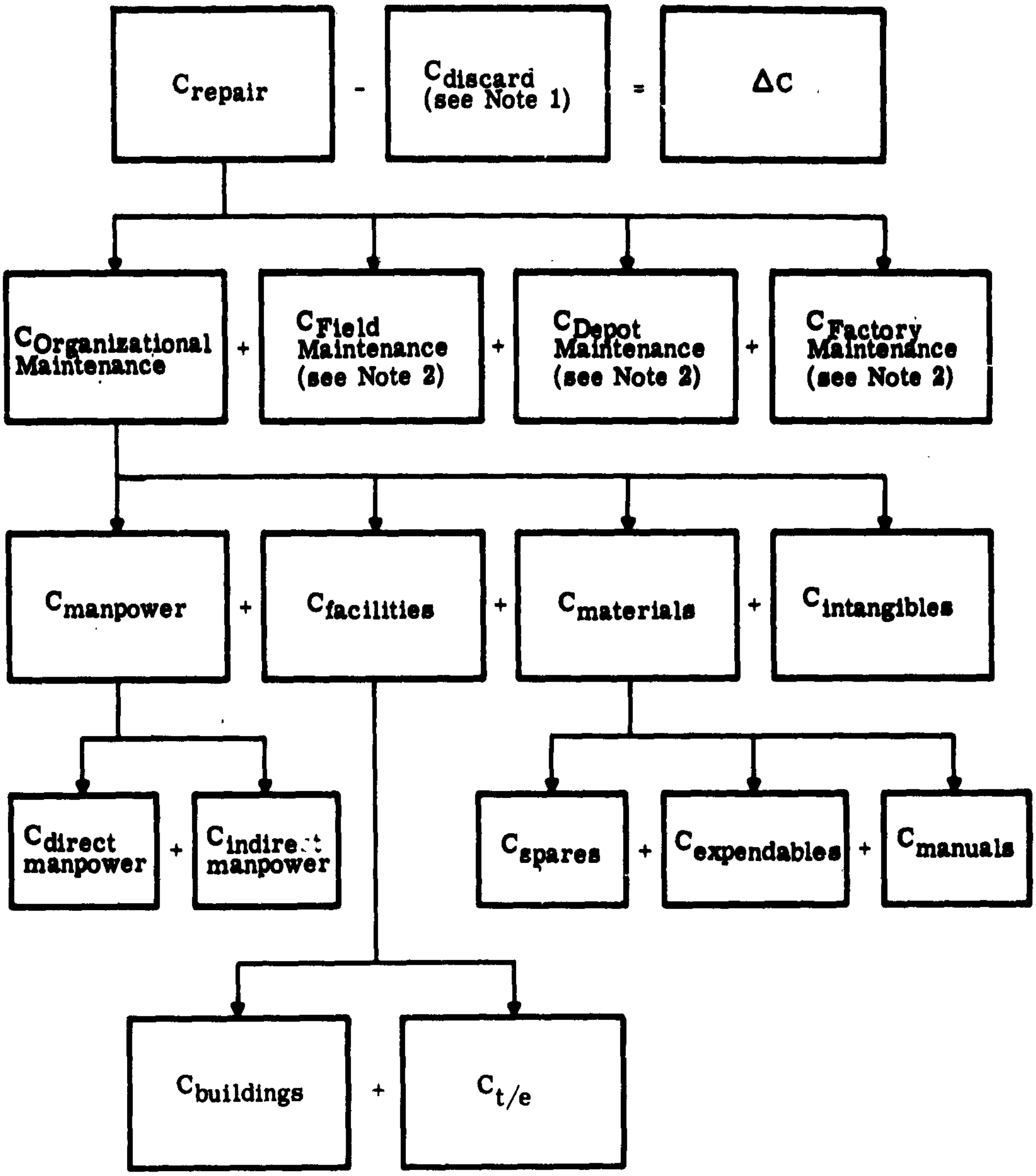
At the first level, the model has the form,

$$C_{repair} - C_{discard} = \Delta C \tag{1}$$

where

C_{repair} = the total dollar resource cost, over the operational life of the modularized equipment designed for corrective maintenance by module repair.

$C_{discard}$ = the total dollar resource cost, over the operational life of the same modularized equipment, but designed for DAF.



Notes: 1. C(discard) also breaks down into costs of organizational, field, depot, and factory maintenance.

2. The costs associated with each maintenance echelon breaks down into the same classes of sub-costs as those shown for organizational maintenance.

Figure 1. Mathematical Model

ΔC = the difference in total dollar resource cost between the two maintenance alternatives, with a positive remainder indicating that the design for DAFM is more economical, and a negative remainder indicating that the design for module repair is more economical.

The model is expressed in the form of a difference to indicate directly, the difference in costs between the two maintenance concepts. In addition, the difference form permits elimination of costs which are independent of the maintenance philosophy (i. e., repair or discard) from the final detailed form of the equation.

Proceeding to the next level of model detail, the resource cost associated with the repair philosophy may be expressed as:

$$C_{\text{repair}} = C_{\substack{\text{organizational}\\ \text{maintenance}}} + C_{\substack{\text{field}\\ \text{maintenance}}} + C_{\substack{\text{depot}\\ \text{maintenance}}} + C_{\substack{\text{factory}\\ \text{maintenance}}} \tag{2}$$

This represents the most generalized form of the equation. If, for example, no maintenance was performed at the manufacturer's plant, the last term of the equation would be equal to zero. Thus, the applicability of each of the cost terms on the right-hand side of equation (2) would be determined by the maintenance plan.

Similarly, the cost of discard can generally be expressed as the sum of the costs of organizational, field, depot and factory maintenance. However, for the DAF case, at least one of the terms on the right side of the equation would normally be zero. Again, the applicability of each of these cost terms would be determined by the maintenance plan.

At the next level of model shred-out, the cost of maintenance at each echelon for either the repair or discard case is equal to the sum of the costs of manpower, facilities, materials and intangibles.

At the third level, manpower costs may be further expanded into direct and indirect labor costs.

Facilities costs may be divided into buildings and test equipment costs, and materials costs into spares, expendables (e.g., wire, solder, encapsulating compounds) and manuals costs. As indicated in Figure 1, the individual terms through the third level of model shred-out are the same for each maintenance echelon for both the repair and discard case. The actual values will, of course, differ.

At the next level of model shred-out, the individual terms will differ, and the following discussion illustrates this difference.

For field and organizational level, the form of the data obtained by the study team was such that the costs associated with direct and indirect manpower, buildings, and test equipment could be handled most conveniently by combining these costs as follows:

$$C_{\substack{\text{direct}\\\text{manpower}}} + C_{\substack{\text{indirect}\\\text{manpower}}} + C_{\text{buildings}} + C_{\substack{\text{test}\\\text{equipment}}}$$

$$= N_R \times \overline{M}_R \times U \left[L_D + B_A + B_N + B_B + B_T \right] \tag{3}$$

where

N_R = total number of repair actions occurring at the maintenance echelon under consideration during the equipment operational life.

$\overline{M}_R$ = average number of man-hours expended per corrective repair action

U = use factor; the ratio of total technician-time available to technician-time spent in active equipment maintenance

L_D = average hourly cost of direct labor including pay and allowances, subsistence, retirement annuity and prorated training costs.

B_A = effective burden rate for administrative personnel in dollars per available direct labor hour.

B_N = effective burden rate for nontechnical personnel in dollars per available direct labor hour.

B_B = effective burden rate for buildings in dollars per available direct labor hour.

B_T = effective burden rate for test equipment in dollars per available direct labor hour.

Direct manpower costs are associated with the personnel who actually perform the repair action. Indirect manpower costs are associated with administrative and management personnel and supply personnel.

The terms N_R and $\overline{M}_R$ are quantities which are calculated for the particular equipment to which the model is applied. N_R is primarily dependent on failure rate, operating hours over the equipment lifetime, amount of equipment supported, and the maintenance plan. All of these factors are normally known or can be estimated at the beginning of a development program. Therefore, N_R can be estimated at an early stage of the design effort.

The quantity $\overline{M}_R$ is a function of many variables - repair level, skill level of maintenance personnel, test equipment effectiveness (in terms of speed, accuracy and reliability), and maintainability design of the prime equipment, to name a few. With the present maintainability prediction methods, values of $\overline{M}_R$ for this particular application, cannot be readily estimated during the early design phases. Therefore, some average value of $\overline{M}_R$ must be provided. Such average values are contained in Appendix I with instructions for the calculations required.

The remaining terms in equation (3) are precalculated quantities which are furnished as model constants. The recommended values of these terms are presented in a later section.

At the depot level, a slightly different grouping of costs is desired. Thus, at depot level, the following grouping is used:

$$C_{\substack{\text{direct}\\ \text{manpower}}} + C_{\substack{\text{administrative}\\ \text{manpower}}} + C_{\text{buildings}} + C_{\substack{\text{test}\\ \text{equipment}}}$$

$$= N_R \times \overline{M}_R \times U \left[L_D + B_A + B_B + B_T \right] \quad (4)$$

where the symbols are as those previously given. The cost of the non-technical personnel needed to support the depot maintenance activity is broken out differently at the depot level to provide model sensitivity to number of line items and number of repaired items. Thus, the cost of non-technical manpower at depot level is:

$$C_{\substack{\text{non-technical}\\ \text{manpower}}} = N_L \left[I + (LxM) \right] + N_{RL} \; (L \times R) + (N_R \times D) \quad (5)$$

where

N_L = number of line items introduced into the supply system

I = cost of introducing a line item into the supply system

L = equipment operational life

M = cost per year of maintaining a line item in the supply system

N_{RL} = number of stock items repaired by the depot

R = cost per year of maintaining a stock item on the Master Repair System (MRS).

N_R = total number of repair actions occurring at the maintenance echelon under consideration (in this case, the depot) during the equipment operational life.

D = debit and credit costs associated with inventory accountability and storage for items repaired at the depot.

The quantities, I, M, R, and D are precalculated model constants. The remaining terms, with the exception of L, are calculated quantities.

The cost of spares is divided into two categories, pipeline spares and spares expended in the repair process. Both of these costs are calculated quantities.

The cost of manuals is relatively insignificant and will be discussed in Section III, subsection D. 1. h.

Originally, it was felt that sufficient data might be available to express certain intangible elements in terms of dollars, however, only scattered data and opinions were available. Therefore, intangible factors will have to be handled as qualitative criteria, and will not be treated mathematically. These intangible factors are discussed in Section III, subsection E.

At the factory maintenance level, the detailed form of the model would depend on the cost accounting structure of the manufacturer. In most instances, the detailed form of the model would be similar to that previously described for organizational and field maintenance.

C. CALCULATION OF MODEL VARIABLES

1. TOTAL NUMBER OF REPAIR ACTIONS, N_R

At the organizational maintenance level, this is the product of the failure rate of the equipment to which the model is being applied, the amount of equipment in operation, and the total number of operating hours over the span of equipment lifetime.

In the model, N_R calculated for organizational maintenance is also used for the number of repair actions occurring at the higher maintenance echelons. For example, each repair action at organizational level will result in one repair action at field level, and if depot repairs are performed, one repair action at depot level.

2. AVERAGE NUMBER OF MAN-HOURS EXPENDED PER REPAIR ACTION, $\overline{M}_R$

As previously stated, this quantity is a function of many variables and for this particular application, cannot be readily predicted. Based on a review of existing and proposed techniques, the following method is recommended for specific use with the model.

The methodology is based on a proposed Bureau of Ships specification, MIL-M-23313 (SHIPS) entitled, "Maintainability Requirements for Shipboard and Shore Electronic Equipment and Systems" dated 12 June 1962. The method was originally developed by the Federal Electric Corporation under Contract NObsr 75376. A final report entitled, "A Maintainability Prediction Procedure for Designers of Shipboard Electronic Equipment and Systems" dated 1 July 1960 also describes the basic prediction method.

The study team modified and simplified the prediction method previously described. The derivation of this modification is described in detail in Appendix I. The method of application is also described in Appendix I.

To obtain $\overline{M}_R$, one further modification is required for the MIL-M-23313 methodology. The value obtained from MIL-M-23313 is in terms of time. To convert this time into man-hours, a conversion equation developed by RCA is used as follows:

$$\log \overline{M}_R = 1.07109 \log T_R + 0.02536$$ [1]

where $\overline{M}_R$ is in man-minutes and $\overline{T}_R$ is the time in minutes calculated from the modified MIL-M-23313 method.

3. SPARES CALCULATIONS

a. Pipeline Spares

The amount of spare parts needed is determined by calculating the number of failures expected for a given time. Spare items are then furnished, within a specified confidence limit, to ensure that there will always be a spare on hand. The period of time used is the repair-cycle time or turn-around-time. A typical example will serve to illustrate the method of calculation.

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[1] See page 18 of RADC-TDR-62-156, "Maintainability Prediction Technique (Phase IV Progress Report)" dated 15 March 1962.

Assume we are calculating the number of spares, of a specific type, needed to support an organizational maintenance activity. The number need cover only those failures which occur between the time the original item fails and the time it is returned to stock as a spare. The expected failures are found by multiplying the failure rate of the unit by system operating nours (during the repair-cycle time) and then by the total number of the units in use.

The number of systems supported by one field shop and the expected number of system operating hours per month would be determined from the maintenance plan. Let us assume the figures are:

- Operating hours/system/month = 50
- Systems supported/field shop = 20
- Units/system = 1
- Failures/hour/unit = 5000×10^{-6}
- Cycle time through field shop/repair = 2.5 days

Then:

$$\text{Expected Failures} = (5000 \times 10^{-6})(50)(20)(1)\left(\frac{2.5}{30}\right)$$

$$= 0.416 \text{ failure}$$

Statistically speaking, the number of expected failures is a mean. This means that 50 percent of the time, the actual number of failures experienced will exceed the expected number of failures. Therefore, if the number of spares equals the expected failures, the confidence level of spares (i.e., the probability that a spare is available when required) would be 50 percent. The number of spares needed to achieve some higher confidence level is obtained from a table of cumulated terms of Poisson's Exponential Binomial Limit (See, Poisson's Exponential Binomial Limit, Table II, by E. C. Molina).

From such a table it can be seen that if 0.416 failure is expected, one or more failures may occur approximately 33 percent of the time, two or more failures approximately 7 percent of the time, and three or more failures approximately 1 percent of the time. Thus to be 99 percent confident that enough spare units of this specific type are on hand to keep the prime equipment operating, two spare units should be stocked at field level. If there are ten operating locations, then 20 units must be procured as spares.

b. <u>Bits and Pieces</u>

As mentioned under the calculation of N_R, the model assumes that repairs made at the organizational level results, on a one-for-one basis, in repair actions at the higher maintenance echelons. For example, replacing a unit by Organizational Maintenance technicians might result in field repair of replacing a single subassembly. The subassembly might then be returned to a depot for replacement of detail parts.

Normally, more than one detail part will be replaced to repair the subassembly. A figure of 3.13 is suggested for use with the model. This figure was obtained from an analysis of ROAMA repair data, and represents an average usage for a random sample of items repaired. (Note: The exact average 3.13, should be used rather than rounding to an even 3.0 parts per repair even though replacing 0.13 of a part has no physical meaning.)

The following relationship is recommended for the calculation of the cost of bits and pieces:

$$C_{\substack{\text{Bits \&}\\ \text{Pieces}}} = \frac{3.13\ N_R}{\begin{pmatrix}\text{Component Count}\\ \text{for Equipment}\\ \text{Supported}\end{pmatrix}} \times \begin{pmatrix}\text{Cost of Equipment}\\ \text{Supported}\end{pmatrix}$$

c. <u>Spare Discard-At-Failure Modules</u>

The quantity of discarded modules is calculated from the following relationship:

$$\begin{matrix}\text{Number of}\\ \text{Spare Modules}\end{matrix} = (\text{Module Failure Rate}) \times \begin{pmatrix}\text{Number of Modules}\\ \text{in Operation}\end{pmatrix} \times \begin{pmatrix}\text{Total Lifetime}\\ \text{Operating Hours}\end{pmatrix}$$

The method of calculation is best illustrated by an example. Assume that the appropriate figures are:

- Module Failure Rate = 50×10^{-6} failures/hour
- Modules of this type/System = 2
- Systems/Location = 1
- Number of Locations = 10
- Operating Hours/System/Month = 500
- System Operational Life = 10 years

Then:

$$\text{Number of Spare Modules per Location} = (50 \times 10^{-6})\,(2 \times 1)\,(500 \times 10 \times 12) = 6$$

With 10 locations, a total of 60 spare modules will be expended over the operational life of the equipment.

4. NUMBER OF LINE ITEMS INTRODUCED INTO THE SUPPLY SYSTEM, N_L

This quantity is the total number of "parts peculiar" introduced into the supply system.

Line items for a particular equipment may be initially categorized as either parts peculiar (i.e., used only in that equipment) or common (i.e., may be used in other equipment). Units, assemblies and subassemblies will normally all be parts peculiar. Common items consist primarily of tubes, resistors, transformers, nuts, screws, etc.

All unique items will incur the introductory cost, I, of $300 per line item. Common items normally undergo a pre-screening action to establish what proportion of these items need an Item Description (I. D.) and a new Federal Stock Number (FSN), and will therefore incur the introductory costs. IBM experience shows that 95 percent of the common items submitted to pre-screening are parts peculiar.

In calculating the number of line items, each type of unit, assembly, subassembly, etc. would be considered a line item. For example, suppose a piece of equipment consists of 10 different units. Further, let us suppose that each unit consists of 24 subassemblies. Of the 240 subassemblies, there are 80 different types, each type being used three times per equipment. The total number of line items represented by the units and subassemblies would be:

$$N_L = 10 \text{ (unit types)} + \frac{10 \times 24}{3} \text{ (subassembly types)} = 90 \text{ line items}$$

At the early design stages, multiple use factors should be estimated, based on past experience with similar kinds of equipment. For example, the degree of multiple use is quite low in radar equipment, but very high for a digital computer.

At the detail part level, some degree of multiple use will normally exist. Experience at IBM shows that the ratio of equipment component-part count to part types will range from 10 to 15. Or, in other words, equipment consisting of 15,000 detail parts will contain 1000 to 1500 part types.

D. MODEL CONSTANTS

1. ORGANIZATIONAL AND FIELD LEVEL

a. Use Factor, U

The use factor accounts for indirect activity and contingency items by maintenance technicians. At organizational and field level, indirect labor performed by indirect labor personnel is accounted for by the burden rates labeled "administrative" and "nontechnical".

The value recommended for use with the model, 4.3, was obtained from RADC TN61-141 entitled "Maintainability Measurement and Prediction Methods for Air Force Ground Electronic Equipment (Phase III Progress Report)", dated 15 June 1961. This value represents the average of 734 observations obtained by a work sampling technique. The 95 percent confidence limits are 4.95 and 3.79.

b. Hourly Direct Labor Rate, LD

The value recommended for use with the model is $3.62 per man-hour. This value was calculated from RADC-TR-60-5 entitled "An Evaluation of Module Replacement and Disposal at Failure for Maintenance of Ground Electronic Equipment," dated 15 December 1958. This figure represents the average of 76 communications maintenance technicians located at six different sites, and includes the following:

- Base Pay
- Quarters Allotment
- Clothing Allowance
- Separate Ration
- Pro-rated Training Costs
- Retirement Annuity

The first four items were based on the rates contained in the "Airman's Pay and Allowance Table" (Effective 1 June 1958). The cost of technical training was based on averages of $110 per week and 29 weeks of training, for a total training cost of $3190 per technician. This was then distributed over the average length of expected technical service.

The retirement annuity was calculated as the present cost, which when paid for 20 years, would return an amount of $215 per month for 29 years. An interest rate of 4 percent compounded semi-annually was used. The cost of the retirement annuity was added to the equivalent rate for the 32 technicians who indicated they planned to remain in service 20 years or more.

Based on the above calculations, an average rate of $7544 per man-year was calculated in RADC-TR-60-5. Total available man-hours per year is equal to 2080 (i.e., 52 weeks × 40 hours/week).

c. Effective Burden Rate for Supervisory Personnel, B_A

The value recommended for use with the model is $1.80 per available direct-labor-hour. This value was also obtained from RADC-TR-60-5, and represents the equivalent pay for every officer either directly or indirectly connected with the maintenance activity, pro-rated to the maintenance personnel.

Based on calculations similar to those used to obtain an equivalent pay for the maintenance personnel, a figure of $3744 per direct labor man-year was obtained. Dividing this by 2080 hours, yields $1.80 per direct-labor-hour.

d. Effective Burden Rate for Nontechnical Support Personnel, B_N

The value recommended for use with the model is $0.19 per available direct-labor-hour. This value was derived from information contained in RADC-TR-60-5.

The cost of nontechnical support personnel is expressed in dollars per equipment year in the referenced report. Therefore, to convert this figure into dollars per available direct-labor-hour, it must be divided by direct labor hours per equipment-year. Table I presents a summary of these calculations.

Table I

COST OF NONTECHNICAL SUPPORT

Site	1	2	3	4	5
Number of Technicians	13	7	8	12	9
Pro-rating Factor	0.40	0.45	0.52	0.92	0.12
Pieces of Equipment	4	4	4	14	4
Direct Labor Hours / Equipment-Year	2704	1638	2163	1640	561.6
Cost of Nontechnical Support Personnel ($/Equipment-Year)	310	0	78	475	174
B_N ($/Direct Labor Hour)	0.1146	0	0.0361	0.2896	0.3098
Avg. B_N = $0.1875 ≈ $0.19 per direct labor hour					

The relationships used in the calculations of Table I are:

$$\frac{\text{Direct-Labor-Hours}}{\text{Equipment-Year}} = \frac{(\text{No. of Technicians})\times(\text{Pro-rating Factor})\times\left(2080\ \frac{\text{hrs}}{\text{man-yr.}}\right)}{(\text{Pieces of Equipment})}$$

and

$$B_N = \left(\begin{array}{c}\text{Cost of Nontechnical}\\ \text{Support Personnel}\end{array}\right) \div \frac{\text{Direct Labor Hours}}{\text{Equipment-Year}}$$

e. Effective Burden Rate for Buildings, B_B

The value recommended for use with the model is \$0.19 per available direct labor hour. This value was derived in a manner similar to that used to obtain B_N. The information used in the calculations was obtained from RADC-TR-60-5. Table II presents a summary of these calculations.

Table II

COST OF BUILDINGS

Site	1	2	3	4	5
Direct Labor Hours / Equipment-Year	2704	1638	2163	1640	561.6
Cost of Buildings (\$/Equipment-Year)	367	305	384	503	70
B_B (\$/Direct-Labor-Hour)	0.1357	0.1862	0.1775	0.3067	0.1246
Average B_N = \$0.1861 ≈ \$0.19 per direct-labor-hour					

The cost of buildings was based on a construction cost of $0.67 per cubic foot and upkeep at $0.07 per cubic foot for cement block construction. An interest rate of 4 percent was used on the capital investment.

f. Effective Burden Rate for Test Equipment, B_T

The value recommended for use with the model is $0.30 per available direct-labor-hour. RADC-TR-60-5 was the source for the information used in the calculations which are summarized in Table III.

Table III

COST OF TEST EQUIPMENT

Site	1	2	3	4	5
Direct-Labor-Hours / Equipment-Year	2704	1638	2163	1640	561.6
Cost of Test Equipment ($/Equipment-Year)	565	604	732	332	201
B_T ($/Direct-Labor-Hour)	0.2089	0.3687	0.3384	0.2024	0.3579
Average B_T = $0.2953 ≈ $0.30 per direct-labor-hour					

This cost was based on an interest rate of 4 percent on the capital investment and a depreciation rate of 10 percent per year. The cost of test equipment maintenance was included in the total cost.

The test equipment which contributed to the above cost consisted of standard items (e.g., oscilloscopes, multimeters, wattmeters, VTVM's, tube testers, signal generators, etc.). With the growing trend toward more complex, automated test equipment, these costs are probably low. Also, with the increased utilization of built-in test features, some of the test equipment costs will be contained in the prime equipment costs. These two factors should be considered during any future model updating programs.

g. Total Labor and Burden Rate

The total organizational and field labor and burden rate recommended for use with the model is the sum of L_D, B_A, B_N, B_B and B_T or $6.10 per available direct-labor-hour. For convenience in application of the model, this figure may be multiplied by the use factor of 4.3 to yield $26.23 per man-hour of active maintenance.

h. **Transportation and Manuals Costs**

These cost categories were insignificant when compared to other costs. The data and calculations used to substantiate this insignificance are shown in Table IV.

Table IV

COMPARATIVE COSTS FOR TRANSPORTATION AND MANUALS

Site	1	2	3	4	5	6
Tech Serv	$10,548	$7,088	$8,440	$6,172	$1,775	$6,251
Nontech Serv	310	0	78	475	174	142
Buildings	367	305	384	503	70	434
Test Equipment	565	604	732	332	201	176
Transportation	0	0	0	58	14	162
Manuals	25.70	12.80	25.70	1.83	25.70	3.10
Total	$11,815.70	$8,009.80	$9,659.70	$7,541.83	$2,259.70	$7,168.10
%Transportation	0%	0%	0%	0.769%	0.620%	2.260%
%Manuals	0.218%	0.160%	0.266%	0.024%	1.137%	0.043%

The figures used for the calculations of Table IV were obtained from RADC-TR-60-5. The statement is also made in this report that if transportation and publications costs are neglected, the error in the calculations will not exceed 10 percent.

The following figures pertaining to the contribution of manuals cost to the total maintenance costs were obtained from a report entitled, "The Expendability of Electronic Assemblies," by the National Bureau of Standards, dated 15 September 1958.

REPAIR:

Cost of manuals	$ 16,000
Total cost of reparable system	$ 3,376,000
Percent manual	0.474%

DAFM:

Cost of manuals	$4,000
Total cost of expendable system	$3,614,000
Percent manual	0.111%

Through discussions with ROAMA personnel, it was determined that transportation costs usually add only 1 or 2 percent to the total procurement cost. Also, in a study performed by Headquarters Air Force Logistics Command, transportation costs were noted as insignificant.

2. DEPOT LEVEL

a. Use Factor, U

The value recommended for use with the model, 1.04, corresponds to industrial manpower use factors and assumes that depot use factors are similar to those of industry.

b. Hourly Direct Labor Rate, L_D

The value recommended for use with the model is $2.75 per man-hour. This figure, obtained from ROAMA personnel, represents an average wage rate for ROAMA maintenance technicians based on the distribution of skills at ROAMA.

c. Effective Total Burden Rate $(B_A + B_B + B_T)$

The value recommended for use with the model is $6.13 per available direct-labor-hour. This figure was also obtained from ROAMA personnel.

d. Total Labor and Burden Rate

The total depot labor and burden rate recommended for use with the model is $2.75 + $6.13 = $8.88 per available direct-labor-hour. For convenience, as was done with field and organizational maintenance labor and burden rates, this figure may be multiplied by the use factor, 1.04. This computation yields $9.24 per man-hour of active maintenance.

e. Cost of Introducing a Line Item Into the Supply System, I

The value recommended for use with the model is $300 per line item.

An extremely wide range of values was found for this cost element ranging from a low of $4 to $25 estimated by ROAMA personnel to a high of $20,000 to $50,000 indicated in a study by the Jet Propulsion Laboratory entitled "Economics and Logistics of Throw-Away Modules," by J. P. Feary and W. A. Collier.

Three hundred dollars, a figure obtained from RADC-TR-60-5, was selected since the report indicated that the estimate was more realistic.

f. Cost of Maintaining a Line Item In the Supply System, M

The value recommended for use with the model is $19 per line item per year. This figure, obtained by Headquarters Air Force Logistics Command, is based on data from ROAMA. Since the method of calculation is rather involved, the calculations are contained in Appendix II.

g. Cost of Maintaining a Line Item on the Depot Material Repair System (MRS), R

The value recommended for use in the model is $29 per line item per year. This figure was also obtained from the Headquarters, Air Force Logistics Command Study and is based on ROAMA data. The calculations, being rather lengthy, are also contained in Appendix II.

h. Debit and Credit Costs, D

The value recommended for use in the model is $14 per reparable[1] item handled by the depot. This figure was also obtained from the Headquarters, Air Force Logistics Command Study and the calculations are contained in Appendix II.

3. FACTORY LEVEL

Use factors, labor rates, and burden rates should be obtained for the particular factory making the repair. For obvious proprietary reasons, a survey of representative industry values could not be made.

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[1] A distinction is made between the terms "reparable" and "repairable". Quoting from AFLCR 63-26, " the term 'reparable' suggests the logistic status of an item rather than the 'condition' of an item. The term 'repairable' is used to describe the condition of a reparable item which is unserviceable and requires repair. "

E. ADDITIONAL FACTORS

1. TOOLS AND EXPENDABLES

Precise data could not be obtained on the cost of tools and expendable items such as wire, solder, etc. A study performed by Headquarters AFLC indicated the following:

- Tooling costs add approximately 0.5 percent to the cost of repair for those items that require $5000.00 or more of special tooling.[1] This figure was an average, based on a sample of 102 items.

- In only one case out of the 102 reviewed was the tooling used solely to repair the item against which it was charged.

- On the average, the tools procured were used to repair eight to ten items in addition to the one against which it was charged.

It was concluded that tooling costs did not contribute significantly to the total repair.

As previously stated, no data was obtained on the cost of materials such as wire, solder, etc. which were expended in the repair operation, and hence the model does not include this cost. Even in extreme cases, the resulting error introduc : into the model would be negligible.

2. INTANGIBLES

Certain intangible factors may contribute significantly to the repair-discard decision. The major factors in this category are the effects of module repair or encapsulation on module reliability, and the problem of spares procurement over the operational life of equipment designed for DAFM. Data obtained on these factors were insufficient to permit inclusion in the model. However, in evaluating the decision resulting from application of the model, these factors should be considered especially when the magnitude of the cost difference between the discard and repair alternatives is small.

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[1] Of the 300 items reviewed, 198 required tooling which cost less than $5000. If the entire 300 items had been used, the 0.5% figure would have been further reduced.

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[1] Of the 300 items reviewed, 198 required tooling which cost less than $5000. If the entire 300 items had been used, the 0.5% figure would have been further reduced.

In one particular case, the indication was that bit-and-piece repair operations increased the failure rate of the repaired modules to almost six times the failure rate of new units. However, this was a unique case of tube-type equipment designed for DAFM, and the decision was reversed when the system became operational. For this reason, it was felt that this data was not applicable to USAF electronic equipment in general.

Extremely limited data for transistorized equipment indicates that an initial burn-in period followed by a carefully controlled bit-and-piece repair of failed modules may improve reliability by uncovering defective components.

In any event, bit-and-piece repair of densely packed modules will subject the module to additional hazards and stresses, thus reducing reliability, unless extreme quality control measures are taken.

Numerous studies and reports allude to the reliability improvement resulting from encapsulation. Improvements ranging from 30 percent to as high as 400 percent are estimated by various manufacturers. Again, no substantiating data is available to establish the exact magnitude of the probable reliability improvement.

The problem of spares procurement over the equipment operational life is discussed in several reports. This represents a serious hindrance for DAF modules. Limited data indicates that factors of 10 or 20 are not uncommon between unit costs on initial procurement and unit costs on subsequent re-procurement. In the extreme, it may be impossible to find a source of re-procurement of low quantity modules. While this factor cannot be summed directly into the total resource cost relationships, it must receive serious consideration in terms of USAF procurement policies, especially on low volume procurements.

F. SIGNIFICANCE OF FACTORS INCLUDED IN THE MODEL

Tables V-A and V-B summarize the calculations performed to substantiate the significance of the factors included in the final form of the mathematical model. The data used for the calculations of Table V-A, for site level costs, were obtained from RADC-TR-60-5. The figures in the table represent the percentage of the cost factors as compared to the total costs incurred at the site. The percentages for any one site do not add up to 100 percent. Transportation and manuals costs, which were not included in the model (see Section III, subsection D. 1. h.), account for a small part of this difference. The major portion of the difference (11 to 22 percent) is due to "distributed initial costs." These costs are primarily the initial equipment purchase price which was not included in the final form of the model. The reason for excluding this cost factor was that since the model is in the form of a difference equation, the difference in the purchase price between an equipment designed for bit-and-piece repair, and one designed for DAFM, would be negligible.

Table V-B contains a summary of similar calculations performed for depot maintenance costs. The basic data used for these calculations were obtained by applying the model to several hypothetical examples.

Table V-A

COMPARATIVE CONTRIBUTION OF FACTORS INCLUDED IN THE MODEL (SITE LEVEL)

Site	1	2	3	4	5	6
% Direct Labor & Supervisory Personnel	66.6	62.7	63.3	59.8	21.7	58.4
% Test Equipment	3.6	5.3	5.5	3.2	2.5	1.6
% Buildings	2.3	2.7	2.9	4.9	0.9	4.1
% Nontechnical Personnel	2.0	—	0.6	4.6	2.2	1.3
% Spare Parts	14.3	13.5	14.3	10.2	49.5	16.7

Table V-B

COMPARATIVE CONTRIBUTION OF FACTORS INCLUDED IN MODEL (DEPOT LEVEL)

Case	I	II	III	IV	V
% Direct Labor	3.2	18.8	21.4	0.1	0.7
% Supervisory Personnel, Buildings & Test Equipment	7.1	42.1	47.7	0.3	1.6
% Nontechnical Personnel	88.4	30.9	22.4	99.5	97.4
% Spare Parts	1.3	8.2	8.5	0.1	0.3

Section IV

METHOD OF MODEL APPLICATION

Section IV

METHOD OF MODEL APPLICATION

From the preceding section describing the mathematical model, it is apparent that the basic form of the model is relatively complex. Since one of the primary objectives of this study has been to formulate a useable model, a simplified method of model application has been developed, and is presented in the following paragraphs.

A. APPLICATION METHOD

1. Extract from the applicable documents (e.g., operational requirements document, procurement specification, etc.) the following information:

   a. Number of operational sites.

   b. Number of pieces of the particular equipment, to which the model will be applied at each operational site.

   c. Number of equipment operating hours per day, week, month or year. Again, only the particular equipment to which the model will be applied is of interest.

2. For the equipment[1] under consideration, define the following quantities as applicable:[2]

   a. Number of functional groups per equipment. (e.g., digital computer equipment might consist of a central computer group and an input/output group.)

   b. Number of units per group. (e.g., the central computer group might contain a memory unit and a logic unit.)

---

[1] It is not considered feasible to apply the model on a subsystem or system level because of the diversity of equipment types and the resulting lack of homogeneity.

[2] The degrees of freedom available in the division of the equipment into units, assemblies, etc. would be limited by the various packaging constraints present in any design situation. Items 2a through 2f are indicative of a typical shred-out.

c. Number of assemblies per unit. (e.g., the logic unit might contain 10 pluggable double-printed circuit card assemblies.)

d. Number of subassemblies per assembly. (e.g., each assembly might consist of two printed circuit cards, mounted in a frame.)

e. Number of stages or circuits per subassembly. (e.g., each printed circuit card might contain a number of circuits such as triggers, logical OR's, logical AND's, etc.)

f. Number of detail parts per stage or circuit.

g. Number of discardable elements contained in 2a through 2f.

3. For the repair case, define the maintenance plan down to detail part level. An example of a reasonable, but hypothetical, maintenance plan might be as follows:

a. Organizational Level - malfunctions localized, with built-in test equipment, to unit level. Repair, by replacing the defective unit.

b. Field Level - malfunctions isolated, with external test equipment, to subassembly level. Repair by replacing the faulty subassembly.

c. Depot Level - malfunctions isolated, with external test equipment, to detail part level. Repair by replacing the defective parts.

d. Factory Level - no factory level maintenance will be required.[1]

---

[1] On many development programs, factory maintenance may be performed during the initial operational phases of the program. This, however, is an interim measure, taken only until the depot builds up a suitable maintenance capability. The difference in costs between maintenance performed at a factory, and the same maintenance performed at a depot, will be slight. Therefore, unless factory maintenance is planned during the <u>entire</u> operational life of the equipment, factory maintenance costs need <u>not be</u> calculated.

4. For the DAF case, one of the variables to be investigated is module size. A reasonable spectrum of module sizes will normally range from modules consisting of a single stage or circuit to modules approaching the size of the element of equipment which is replaced at the organizational echelon of maintenance. At this point, a table, similar to Table VI should be constructed. Such a table will clearly indicate which calculations must be performed.

The maintenance plan for the repair case will be invariant. Presumably, the repair case maintenance plan is developed on basis of the operational requirements of the equipment (e.g., high availability), skill level availability, and workload at the various maintenance echelons. Thus, only one set of calculations are required for the repair case. Calculations are required for the discard case in all instances where the maintenance actions performed at a particular echelon differ from those performed under a repair philosophy.

Normally, the largest feasible siz for a discard module will be the element of the equipment which is replaced at the organizational level. Therefore, in most cases, there will be no difference in the cost of organizational maintenance between the discard and repair cases. Since the model is concerned with cost differences between the discard and repair philosophies, it will usually be unnecessary to calculate organizational maintenance costs. In the event that maintenance differences do exist at the organizational level, the costs are calculated in the same way as field maintenance costs.

5. Calculation of Field (or Organizational) Maintenance Costs (Excluding Spares Cost). (Reference: Equation (3), page 3-5.)

a. Obtain the equipment failure rate. (The Reliability Engineering group would be the source of this information. If the services of such a group are not available, a method such as that contained in ASTIA Document Number AD-148868, "RADC Reliability Notebook" may be used to calculate failure rates.)

b. Determine length of equipment operational life. If no figure is available, assume a 10 year life.

c. Calculate the product of 5a, 5b, 1a, 1b, and 1c, being careful to convert all time values into the same units. A check on this is that all time values should cancel. This value is N_R.

d. Calculate $\overline{M}_R$ using the method and tables contained in Appendix I.

Table VI

TYPICAL GUIDE FOR MODEL CALCULATIONS

Discard-at-Failure Module Size (No. of Parts)	MAINTENANCE ECHELON					
	Organizational		Field		Depot	
	Repair	DAFM	Repair	DAFM	Repair	DAFM
10	Remove and replace units consisting of 400 parts	Same as repair case	Faulty units repaired by removal and replacement of subassemblies consisting of 50 parts	Same as repair case	Faulty subassemblies repaired by replacement of faulty part	Faulty subassemblies repaired by removal and replacement of faulty stages, which are then discarded.
50	Same as for ten-part module	Same as repair case and ten-part module	Same as for ten-part module	Same as for repair case and ten-part module. Decision to discard made at field level.	Same as for ten-part module	—
100	Same as for ten-part module	Same as repair case and ten-part module	Same as for ten-part module	Faulty units repaired by removal and replacement of assemblies consisting of 100 parts. Decision to discard made at field level.	Same as for ten-part module	—
200	Same as for ten-part module	Same as repair case and ten-part module	Same as for ten-part module	Faulty units repaired by removal and replacement of assemblies consisting of 200 parts. Decision to discard made at field level.	Same as for ten-part module	—
400	Same as for ten-part module	Same as repair case and ten-part module	Same as for ten-part module	Faulty units are discarded. Field maintenance activity consists solely of unit failure verification.	Same as for ten-part module	—

Note: Since no factory repair is planned for either a repair or DAFM philosophy, the factory maintenance echelon was not included for this hypothetical example. (See footnote on page 4-3)

e. Multiply the result of 5d by the result obtained in 5c.

f. Multiply the result obtained in 5e by $26.23. This is the cost of maintenance (excluding the cost of spares) at the field (or organizational) level.

This method is used for both the repair and discard cases.

6. Calculation of Field (or Organizational) Spare Bits and Pieces Cost.

a. Proceed to step 6b, if field (or organizational) repair consists of replacement of detail parts. If repair consists of replacement at a higher packaging level than detail parts, determine from the information in the table constructed under step 4, whether the item replaced at the field (or organizational) echelon is reparable at a higher echelon or is a discard module. If the item is reparable, proceed to step 7. If the item is a discard module proceed to step 8.

b. Multiply the product of 5c by 3.13. This is the quantity of spare bits and pieces required at field (or organizational) level.

c. Obtain an estimate of the equipment part count.

d. Divide 6b by 6c. This is the equivalent number of systems which must be provided spare bits and pieces.

e. Obtain an estimate of equipment cost. (Source: Cost Engineering.)

f. Multiply 6d by 6e. This is the cost of spare bits and pieces.

7. Calculation of Field (or Organizational) Cost of Spare Reparable Items.

a. Determine from the maintenance plan the packaging level (i.e., units, assemblies, subassemblies, stages or circuits) of the spare reparable items required to support the field (or organizational) maintenance activity.

b. Obtain the failure rate of the item for which spares will be provided. (Source: Reliability Engineering group or compute, based on method such as that contained in AD-148868.)

c. Estimate the usage of the spare type (i. e., line item) in the equipment.

d. Obtain the repair cycle time for the item. (A reasonable estimate is three days for a shop repaired item and 90 days for a depot or factory repaired item.)

e. Calculate the product of 7b, 7c, 7d, 1b, and 1c, being careful to include any time conversion factors (e.g., hours per week, month per year, etc.) required. The answer is equal to the expected failures of the spare item occurring in the repair cycle at each operating site.

f. Determine the confidence level at which spares will be stocked. If no value is available, use 99 percent.

g. Using the value of expected failures computed in 7e, enter a table of cumulated terms of Poisson's Exponential Binomial limit. (See Table II of E.C. Molina's Poisson's Exponential Binomial Limit.) Determine the number of spares required to achieve the desired confidence level.

h. Multiply the value obtained in 7g by 1a. This is the total number of reparable spares of this type required.

i. Obtain a cost estimate for the reparable spare item. (Source: Cost Engineering.)

j. Multiply 7h by 7i. This is the total cost of reparable spares of this type.

k. Repeat steps 7b through 7j for each reparable spare type needed to support the field (or organizational) maintenance activity. The sum of all such values is the total reparable spare cost at field (or organizational) level.

8. Calculation of Field (or Organizational) Cost of Spare Discard Modules.

a. Obtain the failure rate of the DAF module for which spares will be provided. (Source: Reliability Engineering, or compute, using method such as that contained in AD-148868.)

b. Estimate the usage of the module type (i. e., line item) in the equipment.

c. Calculate the product of 8a, 8b, 5b, 1b, and 1c being careful to include any time conversion factors.

d. Round off the value obtained in 8c to the next highest whole number. If the value is less than one, round off to one.

e. Multiply the whole number obtained in 8d by 1a. This is the total number of spare discard modules of this type required.

f. Obtain a cost estimate for the discard module. (Source: Cost Engineering.)

g. Multiply 8e and 8f. This is the total cost of discard modules of this type.

h. Repeat steps 8a through 8g for each discard module type needed at the field (or organizational) level. The sum of all such values is the total spare discard module cost at field (or organizational) level.

9. Calculation of Depot Maintenance Costs (Excluding Spares and Nontechnical Personnel Costs). (Reference: Equation (4), page 3-6.)

a. The procedure outlined in steps 9 and 10 should be followed if depot repair action is planned. If no depot repair is contemplated, proceed to step 11.

b. Calculate $\overline{M}_R$ using the method and tables contained in Appendix I.

c. Multiply 9b by 5c.

d. Multiply 9c by \$9.24. This is the cost of depot maintenance (excluding spares and nontechnical personnel costs).

This method is used for both the repair and discard cases provided that depot action is planned.

10. Calculation of Depot Spares Cost (Reparable/Bits and Pieces)

a. If depot repair consists of replacing detail parts, perform steps 6b through 6f. If depot repair consists of replacement at a higher packaging level than detail parts, determine, from the information in the table constructed under step 4, whether the item replaced at the depot is reparable

at a factory level or is a discard module. If the item is a factory reparable item, proceed to step 10b. If the item is a discard module, proceed to step 11.

b. Determine from the maintenance plan, the packaging level (i.e., assemblies, subassemblies, stages or circuits) of the factory reparable items needed to support the depot maintenance activity.

c. Obtain the failure rate of the factory reparable item. (Source: Reliability Engineering.)

d. Estimate the usage of the spare type (i.e., line item) in the equipment.

e. Obtain the repair cycle time for the item. (A reasonable estimate for factory repair cycle time is 90 days.)

f. Calculate the product of 10c, 10d, 10e, 1a, 1b and 1c, being careful to include any time conversion factors (e.g., hours per week, months per year, etc.) required. The answer is equal to the expected demand for the factory reparable item occurring in a repair cycle.

g. Determine the confidence level at which spares will be stocked. If no value is available, use 99 percent.

h. Using the value of expected demand computed in 10f, enter a table of cumulated terms of Poisson's Exponential Binomial Limit. (See Table II of E.C. Molina's Poisson's Exponential Binomial Limit.) Determine the number of spare factory reparable items required to achieve the desired confidence level.

i. Obtain a cost estimate for the spare factory reparable item. (Source: Cost Engineering.)

j. Multiply 10h by 10i. This is the total cost of reparable spares of this type.

k. Repeat steps 10c through 10j for each factory reparable spare type needed to support the depot maintenance activity. The sum of all such values is the total cost of factory reparable spares at depot level.

11. Calculation of Depot Cost of Spare Discard Modules.

a. If depot repair does not consist of replacement of discard modules, proceed to step 12. Otherwise, proceed to step 11b.

b. Obtain the failure rate of the DAF module for which spares will be provided. (Source: Reliability Engineering.)

c. Estimate the usage of the module type (i. e., line item) in the equipment.

d. Calculate the product of 11b, 11c, 5b, 1a, 1b, and 1c being careful to include any time conversion factors.

e. Round off the value obtained in 11d to the next highest whole number. If the value is less than one, round off to one. This is the total number of spare discard modules required.

f. Obtain a cost estimate for the discard module. (Source: Cost Engineering.)

g. Multiply 11e by 11f. This is the total cost of discard modules of this type.

h. Repeat steps 11b through 11g for each discard moduie required at the depot level. The sum of all such values is the total spare discard module cost at depot level.

12. Calculation of Depot Nontechnical Personnel Costs. (Reference: Equation (5), page 3-6.)

a. Determine the number of unique line items introduced into the supply system for the specific equipment under consideration. This is simply the sum of the number of unit types, assembly types, etc. For the repair case, this is equal to the number of replaceable element types, not including detail parts. For the discard case, this is also equal to the number of replaceable element types, keeping in mind that the smallest size line item will be the discard module (i. e., the elements which make up the DAF module will not be stock listed, and will therefore not require the line item entry and maintenance costs associated with items which are assigned a FSN and require an I. D.).

b. If depot repair consists of replacement of detail parts, calculate the number of common line items introduced into the supply system by the method outlined in steps 12c through 12f. If depot repair does not include detail part replacement, proceed to step 12g.

c. Estimate the average use of each type part. (A figure of between 10 and 15 is reasonable.)

d. Divide 6c by 12c. This is the total number of detail part types.

e. Estimate the percentage of detail part types requiring the preparation of an Item Description (I. D.). (A reasonable percentage is 95 percent.)

f. Multiply 12e by 12d. This is the number of detail part line items introduced into the supply system.

g. Add the value obtained in 12a to that in 12f. (If steps 12b through 12f were skipped, use the value obtained in 12a.)

h. Multiply 5b by $19.

i. Add $300 to 12h.

j. Multiply 12g by 12i. This is the total cost of introducing and maintaining line items in the supply system.

k. Determine the number of line items repaired by the depot.

l. Calculate the product of 12k, 5b and $29. This is the total cost of maintaining the depot reparable line items on the depot Material Repair System (MRS).

m. Multiply 5c by $14. This is the debit and credit cost which is basically associated with inventory accountability and storage for depot reparable items.

n. Sum 12j, 12l and 12m. This is the total cost of nontechnical depot personnel.

13. Calculation of Factory Maintenance Costs

a. This procedure should only be followed if factory repair action is planned. If no factory repair is contemplated, proceed to step 14.

b. Calculate $\overline{M}_R$ using the method and tables contained in Appendix I.

c. Obtain the use factor for factory maintenance personnel. (A reasonable figure is 1.04.)

d. Obtain the labor and burden rates for factory maintenance personnel applicable to the manufacturer's facility at which the repairs will be made. Calculate the sum of the labor and burden rates.

e. Calculate the product of 13b, 13c, 13d and 5c. This is the "factory cost". (Factory cost is the total cost of labor and burden to provide a specified service.)

f. Determine the ratio of "selling price" to "factory cost" for the manufacturer involved. (Typically, this will range from 1.20 to 1.25.) Selling price is equal to factory cost plus such items as General and Administrative costs, Fee, etc.

g. Multiply 13e by 13f. This is the cost of factory maintenance excluding spares cost.

h. If factory repair consists of replacement of detail parts, perform steps 6b through 6f to obtain the cost of the spare bits and pieces. After performing the calculations indicated proceed to step 14. If factory repair consists of replacement of discard modules, perform step 11 to obtain the cost of spare discard modules, then proceed to step 14.

14. Construct a table similar to Table VII. For a specific case, calculations may not be required for one or more maintenance echelons. A particular maintenance echelon should only be included if <u>both</u> of the following conditions are satisfied:

a. Repair activity for either the repair or discard case is planned at the particular maintenance echelon under consideration.

Table VII

COMPARISON OF REPAIR AND DISCARD COSTS

		Organizational Maintenance			Field Maintenance			Depot Maintenance				Factory Maintenance				
		Mainte-nance (Less spares)	Spares	Total Organi-zational Cost	Mainte-nance (Less spares)	Spares	Total Field Cost	Mainte-nance (Less spares & non-technical manpower)	Spares	Non-technical Manpower	Total Depot Cost	Mainte-nance (Less spares)	Spares	Total Factory Cost	Total Cost	ΔC = Repair-Discard
Repair Philosophy																
DAFM Philosophy																
DAF Module Size (Number of Parts)	10															
	50															
	100															
	200															
	400															

Notes:
1. Calculations may not be required for all four maintenance echelons. See step 14 on page 4-12.
2. The values shown for numbers of parts in the DAF modules are typical. Suitable values should be chosen such that a reasonable spectrum of module sizes is covered. See step 4 on page 4-4.

b. A difference exists between the maintenance actions performed under the repair philosophy and the maintenance actions performed under the DAFM philosophy.

Those maintenance echelons which do not meet these criteria need not be included in the table.

Since the maintenance plan for the repair case is invarient with DAF module size, the total maintenance costs for the repair case are also constant and independent of DAF module size. Therefore, the module size which results in the maximum positive value of ΔC is the optimum size module. Calculations should be made for a sufficient range of module sizes to bracket this optimum DAF module size. When this has been done, additional calculations, using smaller increments of part count (within the bracketed range), may be required to more precisely pinpoint the optimum size.

B. ILLUSTRATIVE EXAMPLE

The following example illustrates the method of model application. The numbering of the steps in the calculations correspond to those contained in the application method outlined in the preceding portion of this section.

1. a. Number of operational sites - 10

   b. Number of pieces of similar equipment at each site - 2

   c. Number of operating hours per equipment - 168 hours/week

2. a. Number of functional groups per equipment - 2

   b. Number of units per group - 3

   c. Number of assemblies per unit - 4

   d. Number of subassemblies per assembly - 2

   e. Number of stages or circuits per subassembly - 5

   f. Number of detail parts per stage or circuit - 10

3. For the repair philosophy, the maintenance plan is as follows:

   a. Organizational Level - Equipment malfunctions will be localized to the unit level using built-in test features. Repair at this level will consist of replacing the defective unit.

b. Field Level - Defective units, identified at organizational level will be transported to a field shop facility. At this level, malfunctions will be isolated to the subassembly level using external test equipment. Repair will consist of replacing the faulty subassembly.

c. Depot Level - Defective subassemblies, identified at field level, will be transported to a depot facility for repair by replacing the defective parts.

4. Suppose that the table constructed as a guide for the calculations is the same as Table VI. Since, for the range of module sizes shown, the organizational maintenance activity is the same for the repair and DAFM cases, no calculations are required for this echelon of maintenance.

5. Calculation of Field Maintenance Costs (Excluding Spares Cost)

a. Equipment failure rate = 240×10^{-6} failures/hour

b. Equipment operational life = 10 years

c. $N_R = (240 \times 10^{-6})\ (10)\ (168)\ (52)\ (10)\ (2) = 419$ failures

$$\text{Check: } \left(\frac{1}{\text{hour}}\right)\ (\text{years}) \left(\frac{\text{hours}}{\text{week}}\right)\left(\frac{\text{weeks}}{\text{year}}\right) : \text{Dimensionless}$$

d. Calculation of $\overline{M}_R$ - From the maintenance plan, isolation is accomplished with external test equipment. The time required to isolate the failure to the subassembly level, using unit test points, is obtained from Table I-2 (Appendix I) at the intersection of the "UNIT" row with the "SUBASSEMBLY" column. The time is 1.417 hours.

The replacement time (disassembly, interchange and reassembly), due to the failure of a subassembly, which is assumed to be pluggable in this case, is obtained from Table I-3 under the "SUBASSEMBLY-PLUGGABLE" heading.

For this example, assume that alignment will not be required. Therefore, alignment time is zero. Checkout will be performed at the unit level, and the time is obtained from Table I-4, under the "UNIT-CHECKOUT" heading. The time is 0.138 hours.

The sum of these task times is equal to $\overline{T}_R$,

$\overline{T}_R = 1.417 + 0.442 + 0.138 = 1.997$ hours

To convert $\overline{T}_R$ into manhours, $\overline{M}_R$, the following equation is used,

$$\log\left[60\ \overline{M}_R\right] = 1.07109 \log\left[(60)\ (1.997)\right] + 0.02536$$

and, solving for $\overline{M}_R$,

$\overline{M}_R = 2.98$ manhours/repair action

e. $5c \times 5d = 419 \times 2.98 = 1249$

f. $5e \times \$26.23 = 1249 \times \$26.23 = \$32,760$

Note: Reference to Table VI will indicate that for this example, this cost is applicable to all Repair cases and to the DAFM cases for modules consisting of 10 and 50 parts. For 100-, 200- and 400-part DAF modules, N_R will be the same, however $\overline{M}_R$ will be different. Therefore, only steps 5d, e and f need be performed for these DAFM cases. In all cases, the DAF module was considered pluggable and alignment was not required. Performance of these calculations for the above DAF module sizes, yields the following results for step 5f:

100-component module - \$26,520

200-component module - \$26,520

400-component module - \$ 1,865

6. Since, for this example, field repair does not consist of replacing detail parts, the cost of field level spares for the module repair case is calculated using the procedure of step 7.

7. a. From the maintenance plan, it is seen that spare assemblies are needed to support the field activity for the repair philosophy.

b. Subassembly failure rate = 5×10^{-6} failures/hour

c. Based on past experience with digital computer equipment of this type, it is estimated that each subassembly will be unique (i.e., the computer will consist of 48 subassemblies, each with a different part number).

d. Depot repair cycle time = 12 weeks

e. 7b × 7c × 7d × 1b × 1c = (5×10^{-6}) (1)(12)(2)(168) = 0.020 failures

Check: $\left(\frac{1}{\text{hr}}\right) \left(\text{weeks}\right) \left(\frac{\text{hours}}{\text{week}}\right)$: Dimensionless

f. Confidence Level = 99%

g. Spares subassemblies required = 1

h. 7g × 1a = 1 × 10 = 10 subassemblies/subassembly type

i. Subassembly cost = $100

j. 7h × 7i = 10 × $100 = $1000 = Spares cost for each subassembly type

k. For this example, let us assume that the calculations performed for each of the 48 subassembly types will be the same as those performed in steps 7a through 7j. Then, the total field spares cost will be 48 × $1000 = $48,000. From the maintenance plan it can be seen that this cost will also be applicable to the 10 component DAF module case. For the remaining DAF module cases step 8 in the procedure will apply.

8. For the 50-part DAF module case, the calculations are as follows:

a. Module failure rate = 5×10^{-6} failures/hour

b. Module use = 1 per equipment

c. 8a × 8b × 5b × 1b × 1c = (5×10^{-6}) (1) (10) (2) (168) (52) = 0.874

Check: $\left(\frac{1}{\text{hour}}\right) \left(\text{years}\right) \left(\frac{\text{hours}}{\text{week}}\right) \left(\frac{\text{weeks}}{\text{year}}\right)$: Dimensionless

d. 0.874 ≈ 1 spare DAF module of this type per location

e. 8d × 1a = 1 × 10 = 10 DAF modules of this type

f. Cost of DAF module = $100

g. 8e × 8f = 10 × $100 = $1000 = spares cost for each DAF module type

h. For this example, let us assume that the calculations performed for each of the 48 DAF module types (50 parts per module) will be the same as those performed in steps 8a through 8g above. Then the total field cost for DAF modules will be 48 × $1000 = $48,000.

If similar calculations are performed for the 100-, 200- and 400-part DAF modules, the following results are obtained:

100-part DAF module = $ 96,000

200-part DAF module = $192,000

400-part DAF module = $332,000

9. Calculation of Depot Maintenance Costs (Excluding Spares and Nontechnical Personnel Costs)

b. Calculation of $\overline{M}_R$ - For the repair case, isolation to the detail part level is accomplished with external test equipment. The isolation time is obtained from Table I-2 at the intersection of the "SUBASSEMBLY" row and the "PART" column. The time is 1.417 hours.

The replacement time, due to the failure of a part, which is soldered-in in this case, is obtained from Table I-3 under the "PART-SOLDERED" heading. The time is 2.696 hours.

For this example, assume that alignment will be required. Alignment and checkout will be performed at the subassembly level, and the time is obtained from Table I-4, under the "SUBASSEMBLY" heading. The time for alignment is 0.045 hours and the checkout time is 0.158 hours.

The sum of these task times is equal to $\overline{T}_R$,

$$\overline{T}_R = 1.417 + 2.696 + 0.045 + 0.158 = 4.316 \text{ hours}$$

and converting to $\overline{M}_R$,

$$\log \left[60\ \overline{M}_R\right] = 1.07109 \log\left[(60)\ (4.316)\right] + 0.02536$$

or,

$\overline{M}_R$ = 6.792 man-hours/repair action

c. 9b × 5c = 6.792 × 419 = 2846

d. 9c × \$9.24 = 2846 × \$9.24 = \$26,297

Similar calculations are performed for the 10-part DAF module as follows:

b. Calculation of $\overline{M}_R$ - The isolation time is obtained from Table I-2 at the intersection of the "SUBASSEMBLY" row and the "STAGE" column. The time is 1.179 hours. The replacement time for a stage which, for this example, is assumed pluggable is obtained from Table I-3 under the "STAGE-PLUGGABLE" heading. The time is 0.608 hours. Again, assume that alignment will be required. Alignment and checkout will be performed at the subassembly level, and the time is obtained from Table I-4 under the "SUBASSEMBLY" heading. The alignment time is 0.045 hours and the checkout time is 0.158 hours.

The sum of these task times is equal to $\overline{T}_R$,

$$\overline{T}_R = 1.179 + 0.608 + 0.045 + 0.158 = 1.990 \text{ hours}$$

and, converting to $\overline{M}_R$,

$$\log\left[60\ \overline{M}_R\right] = 1.07109 \log\left[(60)\ (1.990)\right] + 0.02536$$

or,

$\overline{M}_R$ = 2.965 man-hours/repair action

c. 9b × 5c = 2.965 × 419 = 1242

d. $9c \times \$9.24 = 1242 \times \$9.24 = \$11,476$

For all other DAF module sizes, there is no depot repair and therefore, these costs are zero.

10. For the repair case, depot repair consists of replacement of detail parts. Therefore steps 6b through 6f are performed to determine the bits and pieces spares cost.

6b. $5c \times 3.13 = 419 \times 3.13 = 1311$

6c. Equipment component count = 2400

6d. $6b \div 6c = 1311 \div 2400 = 0.546$

6e. Cost of an equipment = $5500

6f. $6d \times 6e = 0.546 \times \$5500 = \$3003 =$ Cost of spare bits and pieces.

11. For the DAF modules, this step is used to calculate depot spares cost for the 10-component module. (Note: Depot spares are not required for the larger DAF modules.)

b. DAF module failure rate = 1×10^{-6} failures/hour

c. It is estimated that there will be a total of 120 different module types (i.e., average usage of 2 per equipment for each module type).

d. $11b \times 11c \times 5b \times 1a \times 1b \times 1c =$
$(1 \times 10^{-6})\,(2)\,(10)\,(10)\,(2)\,(168)\,(52) = 3.49$

Check: $\left(\frac{1}{\text{hour}}\right)\left(\text{years}\right)\left(\frac{\text{hours}}{\text{week}}\right)\left(\frac{\text{weeks}}{\text{year}}\right)$: Dimensionless

e. $3.49 \approx 4$ spare DAF modules of this type at the depot.

f. Estimated cost of DAF module = $20

g. $11e \times 11f = 4 \times \$20 = \$80$

h. For this example, let us assume that the calculations performed for each of the 120 module types will be the same as those performed in steps 11b through 11g. Then the total depot cost for 10 component DAF modules will be $120 \times \$80 = \$9600$. No depot spares are required for the larger DAF module sizes.

12. Calculation of Depot Nontechnical Personnel Costs

a. For the repair case, the number of unique line items introduced into the supply system is computed as follows:

Number of Unit Types + Number of Assembly Types + Number of Subassembly Types + Number of Circuit Types = 6 + 24 + 48 + 120 = 198 unique line items.

b. For the repair case, the number of common line items is calculated by the precedure of steps 12c through 12f which follow.

c. Average part usage = 12 (See item 12c in Section A.)

d. $6c \div 12c = 2400 \div 12 = 200$ part types

e. Percentage of line items requiring an ID = 95%

f. $12d \times 12e = 200 \times 0.95 = 190$ new part types

g. $12a + 12f = 198 + 190 = 388$

h. $5b \times \$19 = 10 \times \$19 = \$190$

i. $12h + \$300 = \$190 + \$300 = \$490$

j. $12g \times 12i = 388 \times \$490 = \$190,000$

k. Since subassemblies are repaired by the depot, the number of reparable line items is 48.

l. $12k \times 5b \times \$29 = 48 \times 10 \times \$29 = \$13,920$

m. $5c \times \$14 = 419 \times \$14 = \$5866$

n. $12j + 12l + 12m = 190,000 + 13,920 + 5866 = \$209,786$

Similarly, this procedure is performed for the various DAF modules. The results are summarized in Table VIII:

Table VIII

NONTECHNICAL MANPOWER COSTS

DAF Module Size (Component Count)	N_L	N_{RL}	N_R	Cost
10	198	48	419	$116,800
50	78	0	0	$ 38,220
100	30	0	0	$ 14,700
200	18	0	0	$ 8,820
400	6	0	0	$ 2,940

13. Since no factory repair is planned, no factory level calculations are necessary.

14. Construct a table, summarizing the calculations performed. (See Table IX.)

The ΔC column in Table IX shows that 50-part DAF modules result in the lowest cost (maximum positive value of ΔC). Therefore, this is the optimum module size. With the exception of the 400-part DAF module, all of the DAFM philosophies result in less cost than the repair case.

C. POTENTIAL FOR MODEL SIMPLIFICATION

In the course of developing and testing the model, a number of hypothetical cases were formulated, and the model was applied to these cases to determine if the results were reasonable. In one series of calculations, the equipment in the illustrative example was used. The same maintenance plan was used for the repair case. The equipment failure rate, usage and population were varied to evaluate the effect on the optimum module size. The results of these computations are summarized in Table X-A.

Table IX

COMPARISON OF REPAIR AND DISCARD COSTS

		Field Maintenance			Depot Maintenance					
		Maintenance Less Spares	Spares	Total Field Cost	Maintenance (Less spares & nontechnical manpower)	Spares	Nontechnical Manpower	Total Depot Cost	Total Cost	ΔC = Repair-Discard
Repair Philosophy		$32,760	$ 48,000	$ 80,760	$26,297	$3000	$209,800	$239,097	$319,857	
DAFM Philosophy DAF Module Size (No. of Parts)	10	$32,760	$ 48,000	$ 80,760	$11,476	$9600	$116,800	$137,876	$218,636	+$101,221
	50	$32,760	$ 48,000	$ 80,760	0	0	$ 38,220	$ 38,220	$118,980	+$199,030
	100	$26,520	$ 96,000	$122,520	0	0	$ 14,700	$ 14,700	$137,220	+$180,790
	200	$26,520	$192,000	$218,520	0	0	$ 8,820	$ 8,820	$227,340	+$ 90,670
	400	$ 1,865	$336,000	$337,865	0	0	$ 2,940	$ 2,940	$340,805	-$ 22,795

Other equipment was postulated and the model applied. The parameters of this equipment were as follows:

1. Number of parts = 100,000
2. a. Equipment consists of four groups
   b. Each group contains five units
   c. Each unit contains 25 assemblies
   d. Each assembly contains four subassemblies
   e. Each subassembly contains five stages or circuits
   f. Each stage contains 10 parts
3. Maintenance plan for the repair case is as follows:
   a. Organizational maintenance consists of unit replacement
   b. Field maintenance consists of unit repair by replacing defective subassemblies
   c. Depot repair consists of subassembly repair by replacing defective parts.
4. Equipment failure rate = 2000×10^{-6} failures per hour

The computations were made for two conditions of usage and population. The results of these computations are summarized in Table X-B.

Equipment cost was also varied. However, while this changed the total cost picture, the optimum DAF module size remained unchanged. Thus, it appears that the optimum DAF module size may be relatively insensitive to equipment cost variations. In addition, the results summarized in Tables X-A and X-B indicate a trend of inverse proportionality between the product function (i.e., failure rate $\times$ usage $\times$ population) and the size of the optimum DAF module. This suggests the possibility of model simplification, in terms of optimum size DAF module selection. However, such a simplification must be based on many applications of the model to actual equipment, rather than hypothetical cases.

Table X-A

INDICATION OF MODEL TREND

Equipment Failure Rate (failures/hour)	Usage (hours/week)	Population (Amount of equipment)	Optimum DAF Module Size (No. of parts)	Product*
240×10^{-6}	168	2000	10	80.64
240×10^{-6}	168	20	50	0.806
48×10^{-6}	168	20	200	0.161
240×10^{-6}	20	20	400	0.096
*Product of failure rate, usage and population				

Table X-B

INDICATION OF MODEL TREND

Equipment Failure Rate (failures/hour)	Usage (hours/week)	Population (Amount of equipment)	Optimum DAF Module Size (No. of parts)	Product*
2000×10^{-6}	168	2000	10	672.0
2000×10^{-6}	20	20	50	0.800
*Product of failure rate, usage, and population				

Section V

MODEL VALIDITY

Section V

MODEL VALIDITY

A design tool such as the mathematical model developed during this study program presents a rather unique problem in terms of model testing and validation. A decision model by its very nature implies the evaluation of two or more possible alternatives to enable the selection of the best alternative. A complete test of the DAFM decision model would entail developing, manufacturing, and using equipment for which at least two designs had been formulated. One equipment model would be designed for bit-and-piece repair; the other for a DAFM philosophy.

Both equipment designs would then be introduced into the operational inventory; and maintenance, reliability, and cost data would be collected through an extensive field data collection program. The total resource cost predicted by the DAFM decision model would then be compared with the actual resource costs for both equipment designs. The cost of such an extensive program makes this method of model validation highly impractical. Two more practical, though less extensive, approaches to model validation are presented as follows:

- Conduct a field data collection program on several different items of equipment. The items selected should include designs for bit-and-piece repair as well as DAFM. The actual resource costs should be compared with the values predicted by the model.
- Apply the model to several items of equipment which are in the early stages of development. The equipment should be designed in accordance with the best alternative indicated by the model. During equipment operation, feedback data on maintenance, reliability, and cost should be obtained. The actual resource costs would then be compared with the values predicted by the model.

Neither of these approaches to model validation could be performed as a part of this study; however, the study team agreed that both validity tests should be conducted. Such tests would not only provide additional proof of model validity, but would also provide experience in the application and use of the model. In addition, these tests would provide a source of data for future updating of the model constants and indicate possibilities for further model simplification.

Within the scope of this study, the question of model validity can best be answered by examining the precalculated constants provided with the model as well as the methods for calculating model variables.

The Use Factor for organizational and field level maintenance was obtained from RADC TN 61-141. The data contained in this document was based on a sampling of 734 observations. The Use Factor for depot and factory level maintenance corresponds to industrial manpower Use Factors.

The Hourly Direct Labor Rate for organizational and field level maintenance was calculated from data contained in RADC TR 60-5. These data were based on a sampling of 76 Communications maintenance technicians located at six different sites. The depot Hourly Direct Labor Rate was obtained from the Cost Accounting Office at ROAMA.

The Burden Rates for organizational and field level maintenance were also computed from data contained in RADC TR 60-5. These data were based on a sampling of six operational sites. The depot Burden Rate was obtained from the ROAMA Cost Accounting Office.

The precalculated cost factors associated with depot nontechnical support personnel were computed from data obtained from various sources within ROAMA.

The data and tables provided for estimating maintenance time and manhours were based on extensive field data collection programs conducted by RCA and the Federal Electric Corporation.

The number of detail parts per repair action is an average, based on a random sampling of items repaired by ROAMA.

While this particular study did not include extensive field data collection programs, the data used to formulate the model was obtained from previous studies which did include such efforts.

In addition, the model was applied to numerous hypothetical cases. The resulting total maintenance costs predicted by the model ranged from about three to eight times the initial cost of the equipment. This agrees quite closely with various published figures on the ratio of maintenance costs to initial acquisition costs.

Section VI

DESIGN FOR DAFM

Section VI

DESIGN FOR DAFM

A. MICROMINIATURIZATION AND DAFM

For the following discussion, microminiaturization will be defined as any packaging technique which achieves a component part density exceeding 10^5 equivalent parts per cubic foot.

The principal microelectronic approaches are:

1. Discrete component circuits made up of hearing-aid size or pelletized components assembled in various packaging schemes.

2. Integrated circuits in which the component functional parts are produced integrally with, and are inseparable from, the whole. These circuits include:

   a. Thin film integrated circuits formed by printing or vapor-deposition of multicomponent assemblies on flat substrates.

   b. Semiconductor integrated circuits, complete circuits prepared from a solid block of semiconductor material.

3. Hybrid circuits consisting of a partially integrated circuit in combination with discrete components. Since thin film active devices are not yet generally available, thin film hybrid circuits must be used for applications requiring other than resistive and capacitive circuit elements.

For integrated circuits, the question of repair or discard is meaningless since repair is physically impossible. Circuits containing discrete components offer the possibility of repair, however, repair is not normally recommended because of possible damage to other densely packaged components (component leads are frequently as small as 0.003 inch diameter) during the repair operation. Hybrid circuits offer limited repair, however, damage by the repair operation is also possible. Therefore, microminiaturized modules should normally be designed for DAFM. Design for repair will only result in decreasing the magnitude of the actual improvements realized, in terms of reliability, size and weight.

Regardless of whether the microminiaturized module consists of discrete components or integrated circuits, the module may be considered as having an equivalent number of components. At this time, a module having the same form as the discard-repair model, developed under this study, may be used to define an optimum module size. Since the model constants are based on averages for tube and transistor type equipments, some of these constants would change for microminiaturized equipment. Since no data can be obtained on operational microminiaturized equipment, these model constants cannot be accurately determined. However, some definitive statements can be made concerning the impact of microminiaturization on some of the factors entering the discard-repair decision.

Integrated and hybrid circuits are predicted to show an improvement in reliability over discrete component circuits. This improvement is based on extensive use of deposited aluminum interconnections in place of lead soldering and welding. However, the reliability improvement is still largely unproven, and a minimum of three to four years is estimated to establish the reliability of integrated and hybrid circuits.

Based on life tests performed by RCA on communications and digital micromodules, the following conclusions were drawn:

- The micromodule reliability approaches that of an equivalent Minuteman high reliability circuit.
- The micromodule reliability is over five times greater than an equivalent circuit using conventional military components.

Higher reliability will tend to increase the feasible size of the DAF module for a given set of operational conditions.

In short-run quantities, discrete component circuits are the least costly of the microminiaturized circuit types. A key factor in the higher cost of integrated and hybrid circuits is the cost of masks for making the circuits. In early 1962, semiconductor manufacturers quoted mask costs ranging between $1000 and $20, 000. Thin film mask costs are less than those of semiconductors so shorter runs would tend to favor thin-film hybrid circuits over semiconductor integrated circuits. For large quantities, semiconductor integrated circuits have a lower cost potential than circuits fabricated by other means.

Since digital applications have the characteristic of high usage of similar circuits, the earliest significant use of integrated circuits will occur in such applications. Analog integrated circuits, which are still in early development, tend to be more customized, and thus more costly.

According to RCA, by mid-1963 micromodule costs can be expected to be competitive with, and in some cases be less than, the cost of identical circuits using conventional military components mounted on printed circuit cards.

Perhaps the major key to low cost for microminiaturized circuits is standardization. Standardization will insure the high volume usage required to achieve low cost. In addition, standardization will reduce the problem of availability of DAF modules which is one of the major problems associated with the adoption of a DAFM philosophy.

B. PACKAGING FOR DAFM

Since a module designed for DAF need not provide detail part accessibility, hermetic sealing or encapsulation may be used to decrease the stress levels to which the detail parts of the module are subjected. Hermetic sealing primarily provides protection against dust and moisture. Encapsulation provides this same protection more reliably since problems of sealing and development of leaks are not present. In addition, encapsulation provides protection against vibration and shock which may be encountered during use, transportation, and handling. Because of the increased stress protection offered by encapsulation, this packaging method is preferred over that of hermetic sealing in the design of DAF modules.

The reduction in detail part stress levels resulting from encapsulation should also result in increased reliability. Various estimates indicate an improvement in part failure-rates ranging from 30 to 400 percent. The amount of improvement would be primarily dependent on the stress levels encountered by the encapsulated parts and the stress attenuation provided by the encapsulating material.

With the improved detail part failure rates, the failure rate associated with connections and wiring becomes an increasingly important factor in the over-all equipment reliability. Eliminating the need for access to detail parts can result in major reductions (in some instances up to 50%) in the number of connections needed in the equipment. This reduction is accomplished through packaging techniques such as:

- Point-to-point wiring
- Mounting components between two printed circuit boards
- Cordwood packaging in which components are bundled together and interconnected by welding metal ribbons between leads.

In tube-type DAF modules, thermal and reliability considerations may dictate the use of a hybrid module with accessibility provided for the tubes. While effective cooling of encapsulated tubes may be accomplished by bonding the tubes to a heat conducting element which extends into an air stream, perhaps a simpler method is to place the tubes directly in the cooling air stream. This latter approach will permit replacement of failed tubes, which will normally be the high-failure-rate items in a circuit.

Hybrid transistorized DAF modules have been used in various equipment designs. The passive circuit elements are encapsulated while access for repair is provided to the active circuit elements. Based on an evaluation of such a design using the model developed in the study, the use of hybrid DAF modules is not recommended unless dictated by thermal or other packaging limitations. It is felt that in most instances, the use of a hybrid module will result in higher maintenance cost than a corresponding fully encapsulated DAF module.

Similarly, any equipment which uses a combination of DAF and reparable modules will normally represent a sub-optimum design in terms of total maintenance cost.

Section VII

CRITERIA FOR DAFM DESIGN

Section VII

CRITERIA FOR DAFM DESIGN

Previous studies have either implied or specifically stated that the question of optimizing the design for DAFM could be simply resolved by specifying a maximum cost for the DAF module. Unfortunately, the problem is not that simple. As this study indicates, the design for DAFM is a function of a complex interaction of reliability, equipment usage, population and cost, and the maintenance plan. Accordingly, no simple design guidelines can be set regarding DAF module size, cost, or reliability. The optimum DAF module size should be determined, for each design situation, by applying the mathematical model presented in Sections III and IV of this study. Module sizes will vary from those containing a single stage or circuit to those approaching the size of the element of equipment which is replaced at the organizational maintenance level.

The optimum DAF module size will tend to be larger in low-usage low-population equipment than that for high-usage high-population equipment. The reason for this is that the costs of entering and maintaining line items in the supply system will constitute a larger percentage of the total resource costs for the low-usage low-population equipment. Therefore, increasing the DAF module size reduces the number of line items introduced in the supply system, thus reducing the magnitude of line item and maintenance costs.

In addition to the optimum size criteria provided by the DAFM decision model, the following criteria also apply to the DAFM design philosophy.

- DAF modules should normally be encapsulated to reduce shock and vibration stress levels to which the parts and elements of the module are subjected, thereby improving reliability.

- The number of DAF module interconnections should be reduced by such packaging techniques as: (1) Point-to-point wiring, (2) Mounting components between printed circuit boards, and (3) Cordwood packaging in which components are bundled together and interconnected by welding metal ribbons between the leads.

- Hybrid DAF modules should not be used unless dictated by thermal or other packaging limitations. A hybrid DAF module is one in which accessibility is provided to replace active circuit elements. The module is discarded only in the event of failure of an encapsulated passive circuit element.

- Microminiaturized modules containing discrete parts should not be designed for repair by part replacement due to the high susceptibility of such densely packaged modules to damage during the repair operations.

- DAF module types should be standardized to ensure availability of spares throughout the equipment operational life and decrease logistics costs.

- Functional packaging should be utilized to reduce the problems of troubleshooting and test equipment design.

- Test equipment and procedures should be designed to provide rapid location of defective DAF modules.

- Test equipment and procedures applied before disposal of the DAF module should be clearly specified and provide clear-cut results.

Section VIII

CONCLUSIONS AND RECOMMENDATIONS

Section VIII

CONCLUSIONS AND RECOMMENDATIONS

- While the mathematical model developed cannot truly be termed simple, a procedure for application of the model is presented, which, although lengthy, is relatively simple to use.
- In the course of the model development, a number of hypothetical examples were solved. In all instances, DAFM was economically feasible (i.e., resulted in less cost than the repair alternative) at some packaging level in the equipment.
- By selecting a DAFM philosophy early in the design process, packaging techniques can be used which will result in higher reliability for the DAF module than for a comparable reparable module.
- Microminiaturization will force some form of DAFM at the circuit level. Since the optimum module size may be larger than a single circuit, a model similar to that developed in this study should be applied to define the optimum DAF module size for a particular set of conditions.
- Application and use of the model may uncover additional possibilities for model simplification. Such possibilities include computerizing portions of the model, developing a generalized maintenance plan matrix, and developing rapid graphical methods for solving the equations used in the model.
- The model constants should be periodically re-evaluated to establish any impact due to a changing inventory of USAF electronic equipment.
- The model should be applied to actual equipment during its early design stages. Calculations performed during the study on hypothetical equipment indicate the possibility of model simplification in determining an optimum DAF module size. However, such simplification should be based on calculations performed for actual cases, rather than hypothetical examples.
- A field evaluation program to establish model validity could not be performed under this study. However, the results obtained by applying the model to hypothetical cases offer significant evidence of model validity.

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GLOSSARY OF TERMS AND SYMBOLS

A. TERMS

1. FACTORY COST - The total cost of labor and burden to provide a specified service. This cost does not include such items as General and Administrative costs, fee, etc.

2. FEDERAL STOCK NUMBER (FSN) - An eleven-digit number assigned at the Department of Defense level to items of supply throughout the Military Departments. The Federal Stock Number consists of a four-digit code number indicating the Federal Supply Classification (FSC), of an item followed by a seven-digit Federal Item Identification Number (FIIN).

a. Federal Supply Classification (FSC) - Commodity classification designed to serve the functions of supply and logistics, utilizing a four-digit coding structure and presently comprising approximately 74 groups, sub-divided into approximately 500 supply classes.

b. Federal Item Identification Number (FIIN) - A seven-digit number assigned to identify numerically an item within the Federal Catalog Program.

3. LINE ITEM - An item of supply which is listed in a Federal Stock Catalog, and to which is assigned a Federal Stock Number.

4. PIPELINE SPARES - Reparable items which are furnished to a maintenance echelon to provide a spare parts stock. The spare parts stock must be sufficient to cover the expected number of failures of like items during the repair cycle. The repair cycle is the time incurred when the reparable item is sent for repair to a higher echelon of maintenance.

5. REPARABLE - A term applied to items which will be re-conditioned or repaired for re-use when they become unserviceable. The term "reparable" refers to the logistic status of an item as opposed to the term "repairable" which describes the condition of an item.

6. REPAIRABLE - A term used to describe the condition of an item which is unserviceable and requires repair.

7. SELLING PRICE - The factory cost to provide a specified service plus such items as General and Administrative costs, fee, etc. This is the price paid by the Government to obtain the specified service.

8. SPARES PECULIAR - Spare parts which are used on only one line item.

9. SPARES NOT PECULIAR IN CLASS - Spare parts which are used on two or more line items having the same Federal Stock Classification.

10. SPARES NOT PECULIAR OUT OF CLASS - Spare parts which are used on two or more line items having different Federal Stock Classifications.

11. STOCK ITEM - A line item which is classified as reparable.

B. SYMBOLS

N_R = Total number of repair actions occurring at the maintenance echelon under consideration during the equipment operational life.

$\overline{M}_R$ = Average number of man-hours per repair action.

U = Use factor, or the ratio of total technician time available to technician time spent in active equipment maintenance.

L_D = Average hourly cost of direct labor including pay and allowances, subsistence, retirement annuity and prorated training costs.

B_A = Effective burden rate for administrative or supervisory personnel in dollars per available direct labor hour.

B_N = Effective burden rate for nontechnical personnel required to support the active maintenance operation, in dollars per available direct labor hour.

B_B = Effective burden rate for buildings in dollars per available direct labor hour.

B_T = Effective burden rate for test equipment in dollars per available direct labor hour.

N_L = Number of line items introduced into the supply system.

I = Cost of introducing a line item into the supply system.

L = Equipment operational life.

M = Cost per year of maintaining a line item in the supply system.

N_{RL} = Number of line items repaired by the depot.

R = Cost per year of maintaining a stock item on the Material Repair Schedule (MRS).

N_R = Total number of items repaired at the depot during the equipment operational life.

D = Debit and credit costs which are basically costs associated with inventory accountability and storage for items required at the depot.

Appendix I

ESTIMATING AVERAGE MAN-HOURS PER REPAIR ACTION

Appendix I

ESTIMATING AVERAGE MAN-HOURS PER REPAIR ACTION

AVERAGE TIME PER REPAIR ACTION

The method for calculating repair time is based on a method developed by Federal Electric Corporation for the Bureau of Ships. A detailed description of the method is available from the following sources:

- "A Maintainability Prediction Procedure for Designers of Shipboard Electronic Equipment and Systems," by Federal Electric Corporation, dated 1 July 1960.
- MIL-M-23313 (SHIPS), "Maintainability Requirements for Shipboard and Shore Electronic Equipment and Systems," dated 12 June 1962 (this is a proposed specification).

The method described in these two sources is rather complex and requires a certain amount of detailed design information. Accordingly, a simplified method of application was developed to ease the problem of application during the early design phases when little detail is available.

Derivation of Simplified Tables

With the Federal Electric Method, the repair time is obtained by summing the individual times required to perform the following actions:

1. Determining the location of a failure without using accessory test equipment. In other words, isolation using built-in features.
2. Determining the location of a failure to affect repairs by using accessory test equipment and built-in test points.
3. Opening the equipment and disassembling it to make the item that is to be replaced accessible. This does not include the actual removal of the item.
4. Removing the item that is to be replaced and installing the replacement item.

5. Assembling the items that were removed during disassembly, and closing the equipment.

6. Making the necessary alignments and adjustments to return the equipment to satisfactory operation.

7. Verifying, through self-tests or other features, that the equipment has been returned to normal performance.

Tables I-1 through I-4 were derived as follows using the values contained in the charts on page 75 of the Federal Electric Report. (See also page 21 of MIL-M-23313.)

- Table I-1, Localization with Self-Test Features — The data was obtained from the "LOCALIZATION" column in the "PARTS" chart.

- Table I-2, Isolation with External Test Equipment — The data was obtained from the "ISOLATION" column in the "PARTS" chart.

- Table I-3, Replacement — The values shown are the sum of "DISASSEMBLY," "INTERCHANGE," and "REASSEMBLY" times. The data for the Pluggable case were obtained by summing the time from the "DISASSEMBLY" and "REASSEMBLY" columns in the "TUBES" chart and adding an "INTERCHANGE" time of 0.015 hour corresponding to the value for plug-in tubes on page 73 of the Federal Electric Report. (See also page 25 of MIL-M-23313.)

The data for the Solder case were obtained from the sum of the "DISASSEMBLY" and "REASSEMBLY" columns in the "PARTS" chart, together with the "INTERCHANGE" time for parts with two wires or two tabs to be soldered, 0.081 hour on page 75 of the Federal Electric Report.

- Table I-4, Alignment and Checkout — The values were obtained directly from the "ALIGNMENT" and "CHECKOUT" times in the charts. (Note: The "TUBES" and "PARTS" charts are identical.)

METHOD OF APPLICATION OF TABLES

The total repair time in hours is the sum of the applicable maintenance task times obtained from Tables I-1 through I-4. Applicability refers to whether isolation is by means of self-test features, Table I-1, or by external test equipment, Table I-2; whether the item replaced is pluggable or soldered in, Table I-3; and whether testing requires alignment and checkout, Table I-4.

When Table I-1 is used, the desired isolation time is obtained from the intersection of the row representing the functional level at which the isolation feature is effective, and the column representing the level at which replacement will be made. For example, if a system has an isolation feature with built-in test equipment which is effective at the group level, and if the system is to be supported through replacement of a particular assembly whenever a failure occurs within that assembly, the isolation time will be 0.056 hour. This time is obtained from the intersection of the "GROUP" row and "ASSEMBLY" column.

When Table I-2 is used, the same method applies as described for Table I-1. For example, if a system has an isolation feature with external test equipment which is effective at the unit level, and if the system is to be supported through replacement of a particular stage or circuit whenever a failure occurs within that stage, the isolation time will be 1.569 hours. This time is obtained from the intersection of the "UNIT" row and "STAGE OR CIRCUIT" column.

Table I-3 provides immediate access to replacement time, which includes disassembly, interchange, and reassembly times. The times are differentiated according to whether the item replaced is a pluggable or soldered-in type. For example, if the replacement of an assembly, which is pluggable, must be made at the unit level, the replacement time is 0.243 hour. This time is obtained from the "UNIT-PLUGGABLE" location.

Table I-4 provides the alignment and checkout times, as applicable, at the level at which the alignment or checkout is performed. For example, suppose that the final steps in a repair action involving the replacement of a failed assembly in a unit, are alignment of the assembly and checkout of the unit. The alignment time is 0.030 hour, obtained from the "ASSEMBLY-ALIGNMENT" location, and the checkout time is 0.138 hour, obtained from the "UNIT-CHECKOUT" location.

AVERAGE MAN-HOURS PER REPAIR ACTION

Tables I-1 through I-4 provide an estimate of the average time for a repair action. For use in the discard-repair model, this figure must be converted to man-hours. The conversion equation is developed by RCA. (See report entitled "Maintainability Prediction Technique, Phase IV Progress Report," RADC-TDR-62-156, dated 15 March 1962.) The equation is:

$$\log\left[60\ M_R\right] = 1.07109 \log\left[60\ T_R\right] + 0.02536$$

where M_R = average number of man-hours expended per repair action

and T_R = average number of hours per repair action.

Table I-1

LOCALIZATION WITH SELF-TEST FEATURES

Level at Which Test Feature is Effective	Level at Which Replacement is Made							
	Subsystem	Equipment	Group	Unit	Ass'y	Subass'y	Stage or Circuit	Part
System	0.039	0.056	0.073	0.089	0.106	0.121	0.136	0.150
Subsystem	——	0.039	0.056	0.073	0.089	0.106	0.121	0.136
Equipment	——	——	0.039	0.056	0.073	0.089	0.106	0.121
Group	——	——	——	0.039	0.056	0.073	0.089	0.106
Unit	——	——	——	——	0.039	0.056	0.073	0.089
Assembly	——	——	——	——	——	0.039	0.056	0.073
Subassy.	——	——	——	——	——	——	0.039	0.056
Stage	——	——	——	——	——	——	——	0.039

Table I-2

ISOLATION WITH EXTERNAL TEST EQUIPMENT

Level at Which Test Feature is Effective	Level at Which Replacement is Made							
	Subsystem	Equipment	Group	Unit	Ass'y	Subass'y	Stage or Circuit	Part
System	1.179	1.417	1.569	1.700	1.821	1.924	2.022	2.100
Subsystem	——	1.179	1.417	1.569	1.700	1.821	1.924	2.022
Equipment	——	——	1.179	1.417	1.569	1.700	1.821	1.924
Group	——	——	——	1.179	1.417	1.569	1.700	1.821
Unit	——	——	——	——	1.179	1.417	1.569	1.700
Assembly	——	——	——	——	——	1.179	1.417	1.569
Subassy.	——	——	——	——	——	——	1.179	1.417
Stage	——	——	——	——	——	——	——	1.179

Table I-3

REPLACEMENT

Level to Which Disassembly is Made																	
System		Subsystem		Equipment		Group		Unit		Ass'y		Subass'y		Stage or Circuit		Part	
P	S	*P	**S	P	S	P	S	P	S	P	S	P	S	P	S	P	S
0.048	0.114	0.084	0.150	0.125	0.191	0.176	0.242	0.243	0.309	0.328	0.394	0.442	0.508	0.608	0.970	0.766	2.696

*P = Pluggable **S = Soldered

Table I-4

ALIGNMENT AND CHECKOUT

Level at Which Alignment and Checkout are Performed																	
System		Subsystem		Equipment		Group		Unit		Ass'y		Subass'y		Stage or Circuit		Part	
*A	**C	A	C	A	C	A	C	A	C	A	C	A	C	A	C	A	C
0.003	0.062	0.007	0.091	0.010	0.108	0.015	0.124	0.021	0.138	0.030	0.149	0.045	0.158	0.077	0.167	0.156	0.175

*A = Alignment **C = Checkout

Appendix II

CALCULATION OF DEPOT NONTECHNICAL MANPOWER PARAMETERS

Appendix II

CALCULATION OF DEPOT NONTECHNICAL MANPOWER PARAMETERS

The procedure for calculating parameters, M, R, and D, was developed from a study by Oklahoma City Air Materiel Area (OCAMA), using data supplied by Rome Air Materiel Area (ROAMA).

Procedure and Calculations

In the following procedure, raw data and results of calculations are enclosed in parentheses.

1. Parameter M, the cost of maintaining a line item in the supply system.

1.1 Perform the following calculations on a sampling of commodity type items:

a. Divide the number of spares peculiar to the items by the total number of spares needed to overhaul the items (0.712).

b. Divide the number of spares not peculiar in class (i.e., spares used on two or more line items having the same Federal Stock Classification) by the total number of spares needed for overhaul (0.044).

c. Divide the number of spares not peculiar out of class (i.e., spares used on two or more line items having different Federal Stock Classifications) by the total number of spares needed for overhaul (0.244).

1.2 Divide the result of 1.1b by 2 (0.022).

1.3 Divide the result of 1.1c by 10 (0.024).

Note

The result of step 1.1b is divided by 2, and 1.1c by 10 because previous studies (no definite reference was given by OCAMA) showed that spares not peculiar in class would have an average of two applications, and spares not peculiar out of class would have an average of ten applications.

1.4 Sum the results of 1.1a, 1.2 and 1.3 (0.758).

1.5 Determine part of the cost of managing Maintenance and Overhaul (M&O) spares per year per item as follows:

1.5.1 Obtain the number of stock items for the past fiscal year from the quarterly AMC Supply Effectiveness Report (100,972).

1.5.2 Obtain the yearly procurement cost applicable to spares management from the Budget Expense Variance Report ($491,948).

1.5.3 Obtain from Electronic Data Processing Equipment (EDPE) the machine cost for processing a single transaction ($0.20).

1.5.4 Obtain from Financial Inventory Accounting (FIA) the number of transactions for the last fiscal year, and multiply this number by the amount in step 1.5.3 ($492,558).

1.5.5 Obtain the total Base Commander's cost from the Budget Expense Variance Report for the last fiscal year and take 24 percent of this figure[1] ($1600).

1.5.6 Sum the results of 1.5.2, 1.5.4, and 1.5.5, and divide by the total number in 1.5.1 ($9.76).

1.6 Multiply the result of 1.5.6 by the result of 1.4 ($7.40).

1.7 Determine the Main Service Stock (MSS) cost of one stock item per year as follows:

1.7.1 Obtain from the MSS manager the total number of stock items stocked in all the MSS's (14,112).

1.7.2 Obtain a figure for the cost of lights, steel bins, and other equipment assignable to all the MSS's from the Facilities Resources Section under the Materiel Facilities Division, and calculate the depreciation cost for one year on the MSS equipment based on its estimated life ($1,270).

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1. A Rand study indicated that 24 percent of the Base Commander's total cost is allocable to spares management.

1.7.3 Using the Supply Cost and Performance Report (1-AFLC-S-153) for the previous fiscal year, find the total cost for the following:

a. Stock Control Function (59300)[1] ($2,104,299)

b. Storage Function (59500) ($1,646,416)

1.7.4 Obtain the number of employees in functions 59300 and 59500 from the Manpower and Organization strength report and calculate the proportion of each engaged in MSS work. (For 59300: 12/253 = 0.047; for 59500: 8/200 = 0.04.)

1.7.5 Multiply each of the proportions from step 1.7.4 by the total costs in 1.7.3 to obtain the portion of cost of each function which applies to MSS labor (59300: $98,902; 59500: $65,857).

1.7.6 Sum the two results of 1.7.5 and the depreciation cost in 1.7.2 ($166,029). Divide this total by the number obtained in 1.7.1 ($11.76).

1.8 Determine "M" by summing the results of 1.6 and 1.7.6 ($19.16 ≅ $19 per line item per year).

2. Parameter R

2.1 Obtain the Management Analyst Labor Cost ($30,240).

2.2 Obtain the number of line items on the MRS (1050).

2.3 Determine "R" by dividing the value in 2.1 by that in 2.2 ($28.80 ≅ $29 per line item per year).

3. Parameter D

3.1 Obtain the number of debit (552,356) and the number of credit transactions (925,320) for the previous fiscal year from the EDPE Site Workload Summary report.

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1. This number refers to the organizational code.

3.2 Using the S-153 Report for the previous fiscal year, sum the following function costs which pertain solely to debit costs:

a.	Commodity Control	59100	($1,192,816)
b.	Cataloging	59200	($ 695,756)
c.	Inventory	59600	($ 84,199)
			(Sum = $1,972,771)

3.3 Using the S-153 Report, sum the following function costs which pertain solely to credit costs:

a.	Traffic Management	43100	($ 262,519)
b.	Disposal	59700	($ 218,432)
			(Sum = $ 480,951)

3.4 Multiply the machine cost for processing a single transaction (from 1.5.3) by 2 to determine the machine debit and credit cost per stock item ($0.40).

3.5 Sum the following function costs listed in the S-153 Report which pertain to both debit and credit costs:

a.	Warehousing Services	59400	($2,619,812)
b.	The portion of Storage	59500	Not allocated to MSS total labor cost. This is obtained by subtracting the cost obtained in 1.7.5 from the total cost obtained in 1.7.3 ($1,580,559).
c.	The portion of Stock Control	59300	Not allocated to MSS total labor cost. This is obtained by subtracting the cost obtained in 1.7.5 from the total cost obtained in 1.7.3 ($2,005,397).

d.	Transportation	43000	($ 31,945)
e.	Terminal Services	43200	($ 511,280)
f.	Railroad Rolling Stock Operation	92120	($ 208,368)

3.6 Apportion the function costs for Depot Supply Management and General Directorate expense.

3.6.1 Using the S-153 Report, sum the following function costs:

a.	Depot Supply Management	58000	(individual cost not available)
b.	General Directorate Expense	58007	
			(Sum = $ 870,163)

3.6.2 Obtain the number of employees in each of the following functions from the Manpower and Organization strength report:

a.	58000 and 58007	(148)
b.	59100	(134)
c.	59200	(82)
d.	59300	(253)
e.	59400	(330)
f.	59500	(200)
g.	59600	(11)
h.	59700	(29)
i.	43000	(4)
j.	43100	(33)
k.	43200	(62)
l.	92120	(25)

3.6.3 Using the numbers obtained in 3.6.2 and the total cost obtained in 3.6.1, find the portion of this total cost which corresponds to each of the functions in 3.6.2

a.	58000 and 58007	($ 98,241)
b.	59100	($ 88,930)
c.	59200	($ 54,385)
d.	59300	($167,941)
e.	59400	($219,020)
f.	59500	($132,787)
g.	59600	($ 7,309)
h.	59700	($19,231)
i.	43000	($ 2,698)
j.	43100	($21,928)
k.	43200	($41,159
l.	92120	($16,620)

3.6.3.1 Sum the portions for the following functions which represent debit costs only: 59100, 59200, 59600 ($150,624).

3.6.3.2 Sum the portions for the following functions which represent credit costs only: 59700, 43100 ($41,159).

3.6.3.3 Sum the portions for the following functions which represent both debit and credit costs: 58000 and 58007, 59300, 59400, 59500, 43000, 43200, 92120 ($678,466).

3.7 Sum the results in 3.2 and 3.6.3.1 and divide this total by the number of debit transactions obtained in 3.1 ($3.84).

3.8 Sum the results in 3.3 and 3.6.3.2, and divide this total by the number of credit transactions obtained in 3.1 ($0.56).

3.9 Sum the results in 3.5, and 3.6.3.3, and multiply this total by 2. Divide the resulting product by the total number of debit and credit transactions obtained in 3.1 ($10.31).

3.10 Sum the results in 3.4, 3.7, 3.8 and 3.9. This figure represents the total debit and credit cost per line item ($14.71).[1]

3.11 Using the item management record for the prime classes covering any two months which are six months apart:

3.11.1 Obtain the following figures:

a. N_1 = the number of reparable items received, one unit per stock item per shipment, from base level.

b. N_2 = the number received two units per stock item.

c. N_3 = the number received three units per stock item.

d. N_4 = the number received four or more units per stock item.

e. $N = N_1 + N_2 + N_3 + N_4$ = total number of reparable stock items received.

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1 Since reparable items are sometimes received more than one unit per stock item, the result obtained in 3.10 does not represent correctly the debit and credit cost per unit. The factor obtained in 3.11.3 is used to make the necessary corrections.

3.11.2 Calculate the following decimal ratios:

$$P_1 = \frac{N_1}{N} \ (0.96), \quad P_2 = \frac{N_2}{N} \ (0.01),$$

$$P_3 = \frac{N_3}{N} \ (0), \quad P_4 = \frac{N_4}{N} \ (0.03).$$

P_1 is the proportion of reparable items received from base level - one unit per stock item per shipment. P_2 - two units per stock item, P_3 - three units per stock item, and P_4 - four or more units per stock item.

3.11.3 Compute $P_1 + \frac{P_2}{2} + \frac{P_3}{3} + \frac{P_4}{4}$ (0.97).

3.12 Determine "D" by multiplying the result in 3.10 by the result in 3.11.3 ($14.27 ≅ $14 per reparable item handled by the depot).

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